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COMPILATION · OF AIR POLLUTANT EMISSION FACTORS

VOLUME I: STATIONARY POINT AND AREA SOURCES

Office Of Air Quality Planning And Standards Office Of Air And Radiation U. S. Environmental Protection Agency Research Triangle Park, NC 27711

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9.2.2 Pesticide Application

9.2.2.1 General¹⁻²

Pesticides are substances or mixtures used to control plant and animal life for the purposes of increasing and improving agricultural production, protecting public health from pest-borne disease and discomfort, reducing property damage caused by pests, and improving the aesthetic quality of outdoor or indoor surroundings. Pesticides are used widely in agriculture, by homeowners, by industry, and by government agencies. The largest usage of chemicals with pesticidal activity, by weight of "active ingredient" (AI), is in agriculture. Agricultural pesticides are used for cost-effective control of weeds, insects, mites, fungi, nematodes, and other threats to the yield, quality, or safety of food. The annual U. S. usage of pesticide AIs (i. e., insecticides, herbicides, and fungicides) is over 800 million pounds.

Air emissions from pesticide use arise because of the volatile nature of many AIs, solvents, and other additives used in formulations, and of the dusty nature of some formulations. Most modern pesticides are organic compounds. Emissions can result directly during application or as the AI or solvent volatilizes over time from soil and vegetation. This discussion will focus on emission factors for volatilization. There are insufficient data available on particulate emissions to permit emission factor development.

9.2.2.2 Process Description³⁻⁶

Application Methods -

Pesticide application methods vary according to the target pest and to the crop or other value to be protected. In some cases, the pesticide is applied directly to the pest, and in others to the host plant. In still others, it is used on the soil or in an enclosed air space. Pesticide manufacturers have developed various formulations of AIs to meet both the pest control needs and the preferred application methods (or available equipment) of users. The types of formulations are dry, liquid, and aerosol.

Dry formulations can be dusts, granules, wettable and soluble powders, water dispersible granules, or baits. Dusts contain small particles and are subject to wind drift. Dusts also may present an efficacy problem if they do not remain on the target plant surfaces. Granular formulations are larger, from about 100 to 2,500 micrometers (μ m), and are usually intended for soil application. Wettable powders and water-dispersible granules both form suspensions when mixed with water before application. Baits, which are about the same size as granules, contain the AI mixed with a food source for the target pest (e. g., bran or sawdust).

Liquid formulations may be solutions, emulsions (emulsifiable concentrates), aerosols, or fumigants. In a liquid solution, the AI is solubilized in either water or organic solvent. True solutions are formed when miscible liquids or soluble powders are dissolved in either water or organic liquids. Emulsifiable concentrates are made up of the AI, an organic solvent, and an emulsifier, which permits the pesticide to be mixed with water in the field. A flowable formulation contains an AI that is not amenable to the formation of a solution. Therefore, the AI is mixed with a liquid petroleum base and emulsifiers to make a creamy or powdery suspension that can be readily field-mixed with water. Aerosols, which are liquids with an AI in solution with a solvent and a propellant, are used for fog or mist applications. The ranges of optimum droplet size, by target, are 10 to 50 μ m for flying insects, 30 to 50 μ m for foliage insects, 40 to 100 μ m for foliage, and 250 to 500 μ m for soil with drift avoidance.

Herbicides are usually applied as granules to the surface of the soil or are incorporated into the soil for field crops, but are applied directly to plant foliage to control brush and noxious weeds. Dusts or fine aerosols are often used for insecticides but not for herbicides. Fumigant use is limited to confined spaces. Some fumigants are soil-injected, and then sealed below the soil surface with a plastic sheeting cover to minimize vapor loss.

Several types of pesticide application equipment are used, including liquid pumps (manual and power operated), liquid atomizers (hydraulic energy, gaseous energy, and centrifugal energy), dry application, and soil application (liquid injection application).

9.2.2.3 Emissions And Controls^{1,7-14}

Organic compounds and particulate matter are the principal air emissions from pesticide application. The active ingredients of most types of synthetic pesticides used in agriculture have some degree of volatility. Most are considered to be essentially nonvolatile or semivolatile organic compounds (SVOC) for analytical purposes, but a few are volatile (e. g., fumigants). Many widely used pesticide formulations are liquids and emulsifiable concentrates, which contain volatile organic solvents (e. g., xylene), emulsifiers, diluents, and other organics. In this discussion, all organics other than the AI that are liquid under ambient conditions, are considered to have the potential to volatilize from the formulation. Particulate matter emissions with adsorbed active ingredients can occur during application of dusts used as pesticide carriers, or from subsequent wind erosion. Emissions also may contain pesticide degradation products, which may or may not be volatile. Most pesticides, however, are sufficiently long lived to allow some volatilization before degradation occurs.

Processes affecting emissions through volatilization of agricultural pesticides applied to soils or plants have been studied in numerous laboratory and field research investigations. The 3 major parameters that influence the rate of volatilization are the nature of the AI, the meteorological conditions, and soil adsorption.

Of these 3 major parameters, the nature of the AI probably has the greatest effect. The nature of the AI encompasses physical properties, such as vapor pressure, Henry's law constant, and water solubility; and chemical properties, including soil particle adsorption and hydrolysis or other degradative mechanisms. At a given temperature, every AI has a characteristic Henry's law constant and vapor pressure. The evaporation rate of an AI is determined in large part by its vapor pressure, and the vapor pressure increases with temperature and decreases with adsorption of the AI to soil. The extent of volatilization depends in part on air and soil temperature. Temperature has a different effect on each component relative to its vapor pressure. An increase in temperature can increase or decrease volatilization because of its influence on other factors such as diffusion of the AI toward or away from the soil surface, and movement of the water in the soil. Usually, an increase in temperature enhances volatilization because the vapor pressure of the AI increases. Wind conditions also can affect the rate of AI volatilization. Increased wind and turbulence decrease the stagnant layers above a soil surface and increase the mixing of air components near the surface, thus increasing volatilization. The effects of the third major parameter, soil adsorption, depend not only on the chemical reactivity of the AI but to a great extent on the characteristics of the soil. Increased amounts of organic matter or clay in soils can increase adsorption and decrease the volatilization rate of many AIs, particularly the more volatile AIs that are nonionic, weakly polar molecules. The soil

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moisture content can also influence the rate of vaporization of the weakly polar AIs. When soil is very dry, the volatility of the AI is lowered significantly, resulting in a decrease in emissions. The presence of water in the soil can accelerate the evaporation of pesticides because, as water evaporates from the soil surface, the AI present in the soil will be transported to the surface, either in solution or by codistillation or convection effects. This action is called the "wick effect" because the soil acts as a wick for movement of the AI.

Many materials used as inert ingredients in pesticide formulations are organic compounds that are volatile liquids or gases at ambient conditions. All of these compounds are considered to be volatile organic compounds (VOC). During the application of the pesticides and for a subsequent period of time, these organic compounds are volatilized into the atmosphere. Most of the liquid inert ingredients in agriculture pesticide formulations have higher vapor pressures than the Als. However, not all inert ingredients are VOCs. Some liquid formulations may contain water, and solid formulations typically contain nonvolatile (solid) inert ingredients. Solid formulations contain small quantities of liquid organic compounds in their matrix. These compounds are often incorporated as carriers, stabilizers, surfactants, or emulsifiers, and after field application are susceptible to volatilization from the formulation. The VOC inert ingredients are the major contributors to emissions that occur within 30 days after application. It is assumed that 100 percent of these VOC inert ingredients volatilize within that time.

Two important mechanisms that increase emissions are diffusion and volatilization from plant surfaces. Pesticides in the soil diffuse upward to the surface as the pesticide at the soil surface volatilizes. A pesticide concentration gradient is thus formed between the depleted surface and the more concentrated subsurface. Temperature, pesticide concentration, and soil composition influence the rate of diffusion. The rate of volatilization from plant surfaces depends on the manner in which the pesticide covers the plant structure. Higher volatilization losses can occur from plant surfaces when the pesticide is present as droplets on the surface. Volatilization slows when the remaining pesticide is either left in the regions of the plant structure less exposed to air circulation or is adsorbed onto the plant material.

Alternative techniques for pesticide application or usage are not widely used, and those that are used are often intended to increase cost effectiveness. These techniques include (1) use of application equipment that increases the ratio of amount of pesticide on target plants or soil to that applied; (2) application using soil incorporation; (3) increased usage of water-soluble pesticides in place of solvent-based pesticides; (4) reformulation of pesticides to reduce volatility; and (5) use of integrated pest management (IPM) techniques to reduce the amount of pesticide needed. Microencapsulation is another technique in which the active ingredient is contained in various materials that slowly degrade to allow for timed release of pesticides.

9.2.2.4 Emission Factors^{1,15-21}

The variety in pesticide AIs, formulations, application methods, and field conditions, and the limited data base on these aspects combine to preclude the development of single-value emission factors. Modeling approaches have been, therefore, adopted to derive emission factors from readily available data, and algorithms have been developed to calculate emissions for surface application and soil incorporation from product-specific data, supplemented, as necessary, by default values. Emission factors for pesticide AIs, derived through modeling approaches, are given in Table 9.2.2-4. Factors are expressed in units of kilograms per megagram (kg/Mg) and pounds per ton (lb/ton). No emission factors are estimated beyond 30 days because after that time degradation processes (e. g., hydrolysis or microbial degradation) and surface runoff can have major effects on the loss of AIs, and volatilization after that time may not be the primary loss mechanism. The emission factors calculated

using the model are rated "E" because the estimates are derived from mathematical equations using physical properties of the AIs. Because the factors were developed from a very limited data base, resulting emission estimates should be considered approximations. As additional data become available, the algorithm and emission factors will be revised, when appropriate, to incorporate the new data.

This modeling approach estimates emissions from volatilized organic material. No emission estimates were developed for particulate because the available data were inadequate to establish reliable emission factors. The modeled emission factors also address only surface-applied and soil-incorporated pesticides. In aerial application, drift effects predominate over volatilization, and insufficient data are currently available to develop emission factors for this application method.

The model covers the 2 key types of volatilization emissions, (1) those of active (pesticidal) ingredients, and (2) those VOC constituents of the inert (nonpesticidal) ingredients. For some formulations (e. g., liquids and emulsifiable concentrates), emissions of inert VOCs may be an order of magnitude or more higher than those of the AIs, but for other formulations (e. g., granules) the VOC emissions are either relatively less important or unimportant. Thus, both parts of the model are essential, and both depend on the fact that volatilization rates depend in large measure on the vapor pressure of specific ingredients, whether AIs or inerts. Use of the model, therefore, requires the collection of certain information for each pesticide application.

Both the nature of the pesticide and the method by which it is applied must either be known or estimated. Pesticide formulations contain both an AI and inert ingredients, and the pesticide volatilization algorithm is used to estimate their emissions separately. Ideally, the information available for the algorithm calculation will match closely the actual conditions. The following information is necessary to use the algorithm.

- Total quantity of formulation applied;
- Method by which the formulation was applied (the algorithm cannot be used for aerially applied pesticide formulations);
- Name of the specific AI(s) in the formulation;
- Vapor pressure of the AI(s);
- Type of formulation (e. g., emulsifiable concentrate, granules, microcapsules, powder);
- Percentage of inert ingredients; and
- Quantity or percentage of VOC in the inerts.

9.2.2.5 Use Of The Algorithm^{1,18,20}

The algorithm for estimating volatilization emissions is applied in a 6-step procedure, as follows:

- 1. Determine both the application method and the quantity of pesticide product applied.
- 2. Determine the type of formulation used.
- 3. Determine the specific AI(s) in the formulation and its vapor pressure(s).
- 4. Determine the percentage of the AI (or each AI) present.

- 5. Determine the VOC content of the formulation.
- 6. Perform calculations of emissions.

Information for these steps can be found as follows:

- Item 1 The quantity can be found either directly from the weight purchased or used for a given application or, alternately, by multiplying the application rate (e. g., kg/acre) times the number of units (acres) treated. The algorithm cannot be used for aerial application.
- Items 2, 3, and 4 This information is presented on the labels of all pesticide containers. Alternatively, it can be obtained from either the manufacturer, end-use formulator, or local distributor. Table 9.2.2-1 provides vapor pressure data for selected AIs. If the trade name of the pesticide and the type of formulation are known, the specific AI in the formulation can be obtained from Reference 2 or similar sources. Table 9.2.2-2 presents the specific AIs found in several common trade name formulations. Assistance in determining the various formulations for specific AIs applied may be available from the National Agricultural Statistics Service, U. S. Department Of Agriculture, Washington, DC.
- Item 5 The percent VOC content of the inert ingredient portion of the formulation can be requested from either the manufacturer or end-use formulator. Alternatively, the estimated average VOC content of the inert portions of several common types of formulations is given in Table 9.2.2-3.
- Item 6 Emissions estimates are calculated separately for the AI using Table 9.2.2-4, and for the VOC inert ingredients as described below and illustrated in the example calculation.

Emissions Of Active Ingredients -

First, the total quantity of AI applied to the crop is calculated by multiplying the percent content of the AI in the formulation by the total quantity of applied formulation. Second, the vapor pressure of the specific AI(s) at 20 to 25°C is determined from Table 9.2.2-1, Reference 20, or other sources. Third, the vapor pressure range that corresponds to the vapor pressure of the specific AI is found in Table 9.2.2-4. Then the emission factor for the AI(s) is calculated. Finally, the total quantity of applied AI(s) is multiplied by the emission factor(s) to determine the total quantity of AI emissions within 30 days after application. Table 9.2.2-4 is not applicable to emissions from fumigant usage, because these gaseous or liquid products are highly volatile and would be rapidly discharged to the atmosphere.

Emissions Of VOC Inert Ingredients -

The total quantity of emissions because of VOCs in the inert ingredient portion of the formulation can be obtained by using the percent of the inert portion contained in the formulated product, the percent of the VOCs contained in the inert portion, and the total quantity of formulation applied to the crop. First, multiply the percentage of inerts in the formulation by the total quantity of applied formulation to obtain the total quantity of inert ingredients applied. Second, multiply the percentage of VOCs in the inert portion by the total quantity of inert ingredient applied to obtain the total quantity of inert ingredient applied to obtain the total quantity of VOCs in the inert portion by the total quantity of inert ingredient applied to obtain the total quantity of VOC inert ingredients. If the VOC content is not known, use a default value from Table 9.2.2-3 appropriate to the formulation. Emissions of VOC inert ingredients are assumed to be 100 percent by 30 days after application.

Total Emissions -

Add the total quantity of VOC inert ingredients volatilized to the total quantity of emissions from the AI. The sum of these quantities represents the total emissions from the application of the pesticide formulation within 30 days after application.

Example Calculation -

3,629 kg, or 8,000 lb, of Spectracide[®] have been surface applied to cropland, and an estimate is desired of the total quantity of emissions within 30 days after application.

- 1. The active ingredient in Spectracide[®] is diazinon (Reference 2, or Table 9.2.2-2). The pesticide container states that the formulation is an emulsifiable concentrate containing 58 percent active ingredient and 42 percent inert ingredient.
- 2. Total quantity of AI applied:

0.58 * 3,629 kg = 2,105 kg (4,640 lb) of diazinon applied

= 2.105 Mg

2.105 Mg * 1.1 ton/Mg = 2.32 tons of diazinon applied

From Table 9.2.2-1, the vapor pressure of diazinon is 6×10^{-5} millimeters (mm) mercury at about 25 °C. From Table 9.2.2-4, the emission factor for AIs with vapor pressures between 1×10^{-6} and 1×10^{-4} during a 30-day interval after application is 350 kg/Mg (700 lb/ton) applied. This corresponds to a total quantity of diazinon volatilized of 737 kg (1,624 lb) over the 30-day interval.

3. From the pesticide container label, it is determined that the inert ingredient content of the formulation is 42 percent and, from Table 9.2.2.3, it can be determined that the average VOC content of the inert portion of emulsifiable concentrates is 56 percent.

Total quantity of emissions from inert ingredients:

0.42 * 3,629 kg * 0.56 = 854 kg (1,882 lb) of VOC inert ingredients

One hundred percent of the VOC inert ingredients is assumed to volatilize within 30 days.

4. The total quantity of emissions during this 30-day interval is the sum of the emissions from inert ingredients and from the AI. In this example, the emissions are 854 kg (1,882 lb) of VOC plus 737 kg (1,624 lb) of AI, or 1,591 kg (3,506 lb).

Active Ingredient	Vapor Pressure (mm Hg at 20 to 25°C)
1 3-Dichloronronene	20
2 4-D acid	8 0 x 10 ⁻⁶
A combata	1.7 × 10-6
Alashlar	1.7×10^{-5}
Aldicash	1.4×10^{-5}
Aldorusseh	5.0 x 10 0 - 10-5
Andoxycard	9×10^{-10}
Amitraz	2.0×10^{-7}
Amitrole (aminotriazole)	4.4×10^{-7}
Atrazine	2.9×10^{-7}
Azinphos-methyl	2.0 x 10 ⁻⁷
Benefin (benfluralin)	6.6 x 10 ⁻⁵
Benomyl	$< 1.0 \times 10^{-10}$
Bifenox	2.4 x 10 ⁻⁶
Bromacil acid	3.1 x 10 ⁻⁷
Bromoxynil butyrate ester	1.0 x 10 ⁻⁴
Butylate	1.3 x 10 ⁻²
Captan	8.0 x 10 ⁻⁸
Carbaryl	1.2 x 10 ⁻⁶
Carbofuran	6.0 x 10 ⁻⁷
Chlorobenzilate	6.8 x 10 ⁻⁶
Chloroneb	3.0 x 10 ⁻³
Chloropicrin	18
Chlorothalonil	1.0×10^{-3} (estimated)
Chlorpyrifos	1.7 x 10 ⁻⁵
Clomazone (dimethazone)	1.4 x 10 ⁻⁴
Cyanazine	1.6 x 10 ⁻⁹
Cyromazine	3.4 x 10 ⁻⁹
DCNA (dicloran)	1.3 x 10 ⁻⁶
DCPA (chlorthal-dimethyl; Dacthal [®])	2.5 x 10 ⁻⁶
Diazinon	6.0 x 10 ⁻⁵
Dichlobenil	1.0 x 10 ⁻³
Dicofol	4.0 x 10 ⁻⁷
Dicrotofos	1.6 x 10 ⁻⁴
Dimethoate	2.5 x 10 ⁻⁵
Dinocap	4.0 x 10 ⁻⁸

Table 9.2.2-1. VAPOR PRESSURES OF SELECTED ACTIVE INGREDIENTS^a

Active Ingredient	Vapor Pressure (mm Hg at 20 to 25°C)	<u> </u>
Disulfoton	1.5 x 10 ⁻⁴	
Diuron	6.9 x 10 ⁻⁸	
Endosulfan	1.7 x 10 ⁻⁷	
EPTC	3.4×10^{-2}	
Ethalfluralin	8.8 x 10 ⁻⁵	
Ethion	2.4 x 10 ⁻⁶	
Ethoprop (ethoprophos)	3.8 x 10 ⁻⁴	
Fenamiphos	1.0 x 10 ⁻⁶	
Fenthion	2.8 x 10 ⁻⁶	
Fluometuron	9.4 x 10 ⁻⁷	
Fonofos	3.4 x 10 ⁻⁴	
Isofenphos	3.0 x 10 ⁻⁶	
Lindane	3.3 x 10 ⁻⁵	
Linuron	1.7 x 10 ⁻⁵	
Malathion	8.0 x 10 ⁻⁶	
Methamidophos	8.0 x 10 ⁻⁴	
Methazole	1.0 x 10 ⁻⁶	
Methiocarb (mercaptodimethur)	1.2 x 10 ⁻⁴	
Methomyl	5.0 x 10 ⁻⁵	
Methyl parathion	1.5 x 10 ⁻⁵	
Metolachlor	3.1 x 10 ⁻⁵	
Metribuzin	$< 1.0 \times 10^{-5}$	
Mevinphos	1.3 x 10 ⁻⁴	
Molinate	5.6 x 10 ⁻³	
Naled	2.0 x 10 ⁻⁴	
Norflurazon	2.0 x 10 ⁻⁸	
Oxamyl	2.3 x 10 ⁻⁴	
Oxyfluorfen	2.0 x 10 ⁻⁷	
Parathion (ethyl parathion)	5.0 x 10 ⁻⁶	
PCNB	1.1 x 10 ⁻⁴	
Pendimethalin	9.4 x 10 ⁻⁶	
Permethrin	1.3 x 10 ⁻⁸	
Phorate	6.4 x 10 ⁻⁴	
Phosmet	4.9 x 10 ⁻⁷	
Profenofos	9.0 x 10 ⁻⁷	

Table 9.2.2-1 (cont.).

Active Ingredient	Vapor Pressure (mm Hg at 20 to 25°C)
Prometon	7.7 x 10 ⁻⁶
Prometryn	1.2 x 10 ⁻⁶
Propachlor	2.3 x 10 ⁻⁴
Propanil	4.0 x 10 ⁻⁵
Propargite	3.0 x 10 ⁻³
Propazine	1.3 x 10 ⁻⁷
Propoxur	9.7 x 10 ⁻⁶
Siduron	4.0 x 10 ⁻⁹
Simazine	2.2 x 10 ⁻⁸
Tebuthiuron	2.0 x 10 ⁻⁶
Terbacil	3.1 x 10 ⁻⁷
Terbufos	3.2 x 10 ⁻⁴
Thiobencarb	2.2 x 10 ⁻⁵
Thiodicarb	1.0 x 10 ⁻⁷
Toxaphene	4.0 x 10 ⁻⁶
Triallate	1.1 x 10 ⁻⁴
Tribufos	1.6 x 10 ⁻⁶
Trichlorfon	2.0 x 10 ⁻⁶
Trifluralin	1.1 x 10 ⁻⁴
Triforine	2.0 x 10 ⁻⁷

Table 9.2.2-1 (cont.).

^a Reference 20. Vapor pressures of other pesticide active ingredients can also be found there.

Table 9.2.2-2.	TRADE NAMES FOR	R SELECTED	ACTIVE INGREDIENTS
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Trade Names ^b	Active Ingredient ^c
Insecticides	
AC 8911	Phorate
Acephate-met	Methamidophos
Alkron®	Ethyl Parathion
Alleron®	Ethyl Parathion
Aphamite®	Ethyl Parathion
Bay 17147	Azinphos-methyl
Bay 19639	Disulfoton
Bay 70143	Carbofuran

Table	9.2.2-2	(cont.).
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Trade Names ^b	Active Ingredient ^c
Bay 71628	Methamidophos
Benzoepin	Endosulfan
Beosit [®]	Endosulfan
Brodan®	Chlorpyrifos
BugMaster [®]	Carbaryl
BW-21-Z	Permethryn
Carbamine®	Carbaryl
Carfene®	Azinphos-methyl
Cekubaryl®	Carbaryl
Cekudifol [®]	Dicofol
Cekuthoate®	Dimethoate
CGA-15324	Profenofos
Chlorpyrifos 99%	Chlorpyrifos
Chlorthiepin [®]	Endosulfan
Comite®	Propargite
Corothion®	Ethyl Parathion
Crisulfan®	Endosulfan
Crunch®	Carbaryl
Curacron	Profenofos
Curaterr®	Carbofuran
Cyclodan®	Endosulfan
Cygon 400 ⁹	Dimethoate
D1221	Carbofuran
Daphene®	Dimethoate
Dazzel®	Diazinon
Denapon®	Carbaryl
Devicarb®	Carbaryl
Devigon®	Dimethoate
Devisulphan [®]	Endosulfan
Devithion [®]	Methyl Parathion
Diagran [⊕]	Diazinon
Dianon [®]	Diazinon
Diaterr-Fos [®]	Diazinon
Diazajet®	Diazinon
Diazatol®	Diazinon
Diazide®	Diazinon
Dicarbam®	Carbaryl

Table 9.2.2-2 (cont.).

Trade Names ^b	Active Ingredient ^c
Dicomite®	Dicofol
Dimethogen®	Dimethoate
Dimet®	Dimethoate
Dizinon [®]	Diazinon
DPX 1410	Oxamyl
Dyzol®	Diazinon
E-605	Ethyl Parathion
Ectiban [®]	Permethryn
Endocide®	Endosulfan
Endosol®	Endosulfan
ENT 27226	Propargite
ENT27164	Carbofuran
Eradex [®]	Chlorpyrifos
Ethoprop	Ethoprop
Ethoprophos	Ethoprop
Ethylthiodemeton	Disulfoton
Etilon®	Ethyl Parathion
Fezudin	Diazinon
FMC-5462	Endosulfan
FMC-33297	Permethryn
Fonofos	Dyfonate
Force®	Tefluthrin
Fosfamid	Dimethoate
Furacarb®	Carbofuran
G-24480	Diazinon
Gardentox®	Diazinon
Gearphos [®]	Methyl Parathion
Golden Leaf Tobacco Spray®	Endosulfan
Hexavin®	Carbaryl
Hoe 2671	Endosulfan
Indothrin®	Permethryn
Insectophene®	Endosulfan
Insyst-D [®]	Disulfoton
Karbaspray®	Carbaryl
Kayazinon®	Diazinon
Kayazol®	Diazinon
Kryocide®	Cryolite

Trade Names ^b	Active Ingredient ^c
Lannate [®] LV	Methomyl
Larvin [®]	Thiodicarb
Metafos	Methyl Parathion
Metaphos [®]	Methyl Parathion
Methomex [®]	Methomyl
Methyl	Methyl Parathion
Metiltriazotion	Azinphos-methyl
Nipsan®	Diazinon
Niran [®]	Ethyl Parathion
Nivral®	Thiodicarb
NRDC 143	Permethryn
Ortho 124120	Acephate
Orthophos®	Ethyl Parathion
Panthion®	Ethyl Parathion
Paramar®	Ethyl Parathion
Paraphos®	Ethyl Parathion
Parathene®	Ethyl Parathion
Parathion	Methyl Parathion
Parathion	Ethyl Parathion
Farawet®	Ethyl Parathion
Partron M [®]	Methyl Parathion
Penncap-M [®]	Methyl Parathion
Phoskil®	Ethyl Parathion
Piridane®	Chlorpyrifos
Polycron®	Profenofos
PP 557	Permethryn
Pramex®	Permethryn
Prokil®	Cryolite
PT265®	Diazinon
Qamlin [®]	Permethryn
Rampart [®]	Phorate
Rhodiatox [®]	Ethyl Parathion
S276	Disulfoton
SD 8530	Trimethacarb
Septene®	Carbaryl
Sevin 5 Pellets®	Carbaryl
Soprathion [®]	Ethyl Parathion

Table 9.2.2-2 (cont.).

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Trade Names ^b	Active Ingredient ^c
Spectracide®	Diazinon
SRA 5172	Methamidophos
Stathion [®]	Ethyl Parathion
Tekwaisa [®]	Methyl Parathion
Temik [®]	Aldicarb
Tercyl [●]	Carbaryl
Thimul®	Endosulfan
Thiodan	Endosulfan
Thiofor [®]	Endosulfan
Thiophos	Ethyl Parathion
Tricarnam®	Carbaryl
Trimetion®	Dimethoate
UC 51762	Thiodicarb
UC 27867	Trimethacarb
Uniroyal D014	Propargite
Yaltox [®]	Carbofuran
None listed	Dicrotophos
None listed	Terbufos
Herbicides	
A-4D	2,4-D
AC 92553	Pendimethalin
Acclaim	Fenoxaprop-ethyl
Acme MCPA Amine 4®	МСРА
Aljaden®	Sethoxydim
Amiben [®]	Chloramben
Amilon [®] -WP	Chloramben
Amine®	MCPA
Aqua-Kleen [®]	2,4-D
Arrhenal®	DSMA
Arsinyl [®]	DSMA
Assure®	Quizalofop-ethyl
Avadex [®] BW	Triallate
Banlene Plus®	MCPA
Banvel®	Dicamba
Barrage®	2,4-D
Basagran	Bentazon
Bay 30130	Propanil

Table 9.2.2-2 (cont.).

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Table	9.	2.2	-2	(cont.)	•
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Trade Names ^b	Active Ingredient ^c
Bay DIC 1468	Metribuzin
Bay 94337	Metribuzin
Benefex [●]	Benefin
Benfluralin	Benefin
Bentazon	Bentazon
Bethrodine	Benefin
BH [®] MCPA	МСРА
Bioxone®	Methazole
Blazer®	Aciflurofen
Bolero®	Thiobencarb
Border-Master [®]	МСРА
Brominex [®]	Bromoxynil
C-2059	Fluometuron
Cekuiron®	Diuron
Cekuquat [®]	Paraquat
Cekusima [©]	Simazine
CGA-24705	Metolachlor
Checkmate [®]	Sethoxydim
Chloroxone®	2,4-D
Classic [®]	Chlorimuron-ethyl
Clomazone	Clomazone
Command®	Clomazone
CP50144	Alachlor
Crisuron®	Diuron
Croprider®	2,4-D
Dacthal®	DCPA
Dailon®	Diuron
Depon®	Fenoxaprop-ethyl
Dextrone®	Paraquat
Di-Tac [®]	DSMA
Diater®	Diuron
DMA	DSMA
DMA-100 [®]	DSMA
DPA	Propanil
DPX-Y6202	Quizalofop-ethyl
EL-110	Benefin
EL-161	Ethalfluralin

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Table 9.2.2-2 (cont.).

.

Trade Names ^b	Active Ingredient ^c
Emulsamine®	2,4-D
Esgram [⊕]	Paraquat
Excel [©]	Fenoxaprop-ethyl
EXP-3864	Quizalofop-ethyl
Expand®	Sethoxydim
Far-Go®	Triallate
Farmco Diuron [®]	Diuron
Farmco Atrazine Gesaprim®	Atrazine
Fervinal [●]	Sethoxydim
Ferxone®	2,4-D
Furore®	Fenoxaprop-ethyl
Fusilade 2000	Fluazifop-p-butyl
G-30027	Atrazine
G-34161	Prometryn
G-34162	Ametryn
Gamit [®]	Clomazone
Genate Plus [®]	Butylate
Glyphosate Isopropylamine Salt	Glyphosate
Goldquat [®] 276	Paraquat
Grasidim®	Sethoxydim
HerbAll®	MSMA
Herbaxon®	Paraquat
Herbixol●	Diuron
Higalcoton®	Fluometuron
Hoe 002810	Linuron
Hoe-023408	Diclofop-methyl
Hoe-Grass®	Diclofop-methyl
Hoelon®	Diclofop-methyl
Illoxan [®]	Diclofop-methyl
Kilsem [●]	МСРА
Lasso	Alachlor
Lazo®	Alachlor
Legumex Extra [®]	МСРА
Lexone [®] 4L	Metribuzin
Lexone [®] DF [®]	Metribuzin
Linorox®	Linuron
LS 801213	Aciflurofen

Trade Names ^b	Active Ingredient ^c
M.T.F.®	Trifluralin
Magister®	Clomazone
Mephanac®	МСРА
Merge 823 [®]	MSMA
Methar [®] 30	DSMA
Mezopur®	Methazole
Monosodium methane arsenate	MSMA
Nabu [®]	Sethoxydim
Option [®]	Fenoxaprop-ethyl
Oxydiazol	Methazole
Paxilon [®]	Methazole
Pillarquat®	Paraquat
Pillarxone®	Paraquat
Pillarzo®	Alachlor
Pilot [®]	Quizalofop-ethyl
Plantgard [®]	2,4-D
Pledge®	Bentazon
PP 005	Fluazifop-p-butyl
Primatol Q [®]	Prometryn
Probe	Methazole
Prop-Job [®]	Propanil
Propachlor	Propachlor
Prowl®	Pendimethalin
Rattler®	Glyphosate
RH-6201	Aciflurofen
Rodeo [®]	Glyphosate
Roundup®	Glyphosate
S 10145	Propanil
Sarclex®	Linuron
Saturno®	Thiobencarb
Saturn®	Thiobencarb
Scepter®	Imazaquin
SD 15418	Cyanazine
Sencor [®] 4	Metribuzin
Sencor [®] DF	Metribuzin
Shamrox®	МСРА
Sodar®	DSMA

Table 9.2.2-2 (cont.).

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Table 9.2.2-2 (cont.).

Trade Names ^b	Active Ingredient ^c			
Sonalan®	Ethalfluralin			
Squadron®	Imazaquin			
Squadron®	Pendimethalin			
Strel [©]	Propanil			
Surpass [®]	Vernolate			
Targa®	Quizalofop-ethyl			
Target MSMA [®]	MSMA			
Telok®	Norflurazon			
Tigrex [®]	Diuron			
Total®	Paraquat			
Toxer®	Paraquat			
Trans-Vert [®]	MSMA			
Tri-4®	Trifluralin			
Tri-Scept [®]	Imazaquin			
Tributon®	2,4-D			
Trifluralina 600®	Trifluralin			
Trinatox D [®]	Ametryn			
Tritex-Extra [®]	Sethoxydim			
Tunic®	Methazole			
Unidron [®]	Diuron			
VCS 438	Methazole			
Vegiben [⊕]	Chloramben			
Vernam 10G	Vernolate			
Vernam 7E	Vernolate			
Vonduron [®]	Diuron			
Weed-Rhap [®]	МСРА			
Weed-B-Gon [®]	2,4-D			
Weedatul®	2,4-D			
Weedtrine-II [®]	2,4-D			
Whip●	Fenoxaprop-ethyl			
WL 19805	Cyanazine			
Zeaphos®	Atrazine			
Zelan [®]	МСРА			
None listed	EPTC			
None listed	Fomesafen			
None listed	Molinate			
None listed	Tridiphane			

Table 9.2.2-2 (cont.).

Trade Names ^b	Active Ingredient ^c		
Other Active Ingredients			
A7 Vapam®	Metam Sodium		
Aquacide®	Diquat		
Avicol®	PCNB		
Carbam (MAF)	Metam Sodium		
Clortocaf Ramato®	Chlorothalonil		
Clortosip [®]	Chlorothalonil		
Cotton Aide HC®	Cacodylic		
De-Green®	Tribufos		
DEF®	Tribufos		
Deiquat	Diquat		
Dextrone®	Diquat		
E-Z-Off D [®]	Tribufos		
Earthcide®	PCNB		
Exotherm Termil [®]	Chlorothalonil		
Folex®	Tribufos		
Folosan®	PCNB		
Fos-Fall A [•]	Tribufos		
Karbation [®]	Metam Sodium		
Kobutol®	PCNB		
Kobu®	PCNB		
Kypman [©] 80	Maneb		
M-Diphar [®]	Maneb		
Mancozin®	Mantozeb		
Maneba [®]	Maneb		
Manebe	Maneb		
Manzate [®] 200	Mancozeb		
Manzeb	Mancozeb		
Manzin®	Mancozeb		
Maposol®	Metam Sodium		
Metam for the Acid	Metam Sodium		
Moncide®	Cacodylic		
Montar [®]	Cacodylic		
Nemispor [®]	Mancozeb		
Pentagen®	PCNB		
Quintozene	PCNB		
Rad-E-Cate [®] 25	Cacodylic		

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Table	9.2.2-2	(cont.).
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Trade Names ^b	Active Ingredient ^c
Reglon	Diquat
Riozeb®	Mancozeb
RTU [®] PCNB	PCNB
Sectagon [®] II	Metam Sodium
SMDC	Metam Sodium
Soil-Prep [®]	Metam Sodium
Sopranebe®	Maneb
Superman [®] Maneb F	Maneb
Terrazan®	PCNB
Tersan 1991 [®]	Benomyl
TriPCNB®	PCNB
Tubothane®	Maneb
Weedtrine-D [®]	Diquat
Ziman-Dithane [®]	Mancozeb
None listed	Dimethipin
None listed	Ethephon
None listed	Thiadiazuron

^a Reference 2. See Reference 22 for selected pesticides used on major field crops.

^b Reference 2.

^c Common names. See Reference 2 for chemical names.

Table 9.2.2-3.AVERAGE VOC CONTENT OF PESTICIDE INERT INGREDIENT
PORTION, BY FORMULATION TYPE^a

Formulation Type	Average VOC Content Of Inert Position (wt. %)			
Oils	66			
Solution/liquid (ready to use)	20			
Emulsifiable concentrate	56			
Aqueous concentrate	21			
Gel, paste, cream	40			
Pressurized gas	29			
Flowable (aqueous) concentrate	21			
Microencapsulated	23			
Pressurized liquid/sprays/foggers	39			
Soluble powder	12			
Impregnated material	38			

Formulation Type	Average VOC Content Of Inert Position (wt. %)
Pellet/tablet/cake/briquette	27
Wettable powder	25
Dust/powder	21
Dry flowable	28
Granule/flake	25
Suspension	15
Paint/coatings	64

Table 9.2.2-3 (cont.).

^a Reference 21.

Table 9.2.2-4 (Metric And English Units). UNCONTROLLED EMISSION FACTORS FOR PESTICIDE ACTIVE INGREDIENTS^a

EMISSION FACTOR RATING: E

Vapor Pressure Pange	Emission Factor ^c		
(mm Hg at 20 to 25°C) ^b	kg/Mg	lb/ton	
Surface application (SCC 24-61-800-001) 1×10^{-4} to 1×10^{-6} > 1×10^{-4}	350 580	700 1,160	
Soil incorporation (SCC 24-61-800-002) $< 1 \times 10^{-6}$ 1×10^{-4} to 1×10^{-6} $> 1 \times 10^{-4}$	2.7 21 52	5.4 42 104	

^a Factors are functions of application method and vapor pressure. SCC = Source Classification Code.

^b See Reference 20 for vapor pressures of specific active ingredients.

^c References 1,15-18. Expressed as equivalent weight of active ingredients volatilized/unit weight of active ingredients applied.

References For Section 9.2.2

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9.2.3 Orchard Heaters

9.2.3.1 General¹⁻⁶

Orchard heaters are commonly used in various areas of the United States to prevent frost damage to fruit and fruit trees. The 5 common types of orchard heaters—pipeline, lazy flame, return stack, cone, and solid fuel—are shown in Figure 9.2.3-1. The pipeline heater system is operated from a central control and fuel is distributed by a piping system from a centrally located tank. Lazy flame, return stack, and cone heaters contain integral fuel reservoirs, but can be converted to a pipeline system. Solid fuel heaters usually consist only of solid briquettes, which are placed on the ground and ignited.

The ambient temperature at which orchard heaters are required is determined primarily by the type of fruit and stage of maturity, by the daytime temperatures, and by the moisture content of the soil and air.

During a heavy thermal inversion, both convective and radiant heating methods are useful in preventing frost damage; there is little difference in the effectiveness of the various heaters. The temperature response for a given fuel rate is about the same for each type of heater as long as the heater is clean and does not leak. When there is little or no thermal inversion, radiant heat provided by pipeline, return stack, or cone heaters is the most effective method for preventing damage.

Proper location of the heaters is essential to the uniformity of the radiant heat distributed among the trees. Heaters are usually located in the center space between 4 trees and are staggered from 1 row to the next. Extra heaters are used on the borders of the orchard.

9.2.3 Emissions^{1,6}

Emissions from orchard heaters are dependent on the fuel usage rate and the type of heater. Pipeline heaters have the lowest particulate emission rates of all orchard heaters. Hydrocarbon emissions are negligible in the pipeline heaters and in lazy flame, return stack, and cone heaters that have been converted to a pipeline system. Nearly all of the hydrocarbon losses are evaporative losses from fuel contained in the heater reservoir. Because of the low burning temperatures used, nitrogen oxide emissions are negligible.

Emission factors for the different types of orchard heaters are presented in Table 9.2.3-1 and Figure 9.2.3-2. Factors are expressed in units of kilograms per heater-hour (kg/htr-hr) and pounds per heater-hour (lb/htr-hr).



9.2.3-2

EMISSION FACTORS





Figure 9.2.3-2. Particulate emissions from orchard heaters.^{3,6}

i	Type Of Heater					
Pollutant	Pipeline	Lazy Flame	Return Stack	Cone	Solid Fuel	
Particulate kg/htr-hr lb/htr-hr	b b	b b	b b	b b	0.023 0.05	
Sulfur oxides ^c kg/htr-hr lb/htr-hr	0.06S ^d 0.13S	0.05S 0.11S	0.06S 0.14S	0.06S 0.14S	ND ND	
Carbon monoxide kg/htr-hr lb/htr-hr	2.8 6.2	ND ND	ND ND	ND ND	ND ND	
VOCs ^e kg/htr-hr lb/htr-hr	Neg Neg	7.3 16.0	7.3 16.0	7.3 16.0	Neg Neg	
Nitrogen oxides ^f kg/htr-hr lb/htr-hr	Neg Neg	Neg Neg	Neg Neg	Neg Neg	Neg Neg	

EMISSION FACTOR RATING: C

^a References 1,3-4, and 6. ND = no data. Neg = negligible.

^b Particulate emissions for pipeline, lazy flame, return stack, and cone heaters are shown in Figure 9.2.3-2.

^c Based on emission factors for fuel oil combustion in Section 1.3.

^d S = sulfur content.

^e Reference 1. Evaporative losses only. Hydrocarbon emissions from combustion are considered negligible. Evaporative hydrocarbon losses for units that are part of a pipeline system are negligible.

^f Little nitrogen oxides are formed because of the relatively low combustion temperatures.

References For Section 9.2.3

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- 2. Frost Protection In Citrus, Agricultural Extension Service, University Of California, Ventura, CA, November 1967.
- 3. Personal communication with Mr. Wesley Snowden, Valentine, Fisher, And Tomlinson, Consulting Engineers, Seattle, WA, May 1971.
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- 5. Communication with Agricultural Extension Service, University Of California, Ventura, CA, October 1969.
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EMISSION FACTORS

9.3 Harvesting Operations

- 9.3.1 Cotton Harvesting
- 9.3.2 Grain Harvesting
- 9.3.3 Rice Harvesting
- 9.3.4 Cane Sugar Harvesting

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9.3.1 Cotton Harvesting

9.3.1.1 General

Wherever it is grown in the U. S., cotton is defoliated or desiccated prior to harvest. Defoliants are used on the taller varieties of cotton that are machine picked for lint and seed cotton, and desiccants usually are used on short, stormproof cotton varieties of lower yield that are harvested by mechanical stripper equipment. More than 99 percent of the national cotton area is harvested mechanically. The 2 principal harvest methods are machine picking, with 70 percent of the harvest from 61 percent of the area, and machine stripping, with 29 percent of the harvest from 39 percent of the area. Picking is practiced throughout the cotton regions of the U. S., and stripping is limited chiefly to the dry plains of Texas and Oklahoma.

Defoliation may be defined as the process by which leaves are abscised from the plant. The process may be initiated by drought stress, low temperatures, or disease, or it may be chemically induced by topically applied defoliant agents or by overfertilization. The process helps lodged plants to return to an erect position, removes the leaves that can clog the spindles of the picking machine and stain the fiber, accelerates the opening of mature bolls, and reduces boll rots. Desiccation by chemicals is the drying or rapid killing of the leaf blades and petioles, with the leaves remaining in a withered state on the plant. Harvest-aid chemicals are applied to cotton as water-based spray, either by aircraft or by a ground machine.

Mechanical cotton pickers, as the name implies, pick locks of seed cotton from open cotton bolls and leave the empty burs and unopened bolls on the plant. Requiring only 1 operator, typical modern pickers are self-propelled and can simultaneously harvest 2 rows of cotton at a speed of 1.1 to 1.6 meters per second (m/s) (2.5 - 3.6 miles per hour [mph]). When the picker basket gets filled with seed cotton, the machine is driven to a cotton trailer at the edge of the field. As the basket is hydraulically raised and tilted, the top swings open allowing the cotton to fall into the trailer. When the trailer is full, it is pulled from the field, usually by pickup truck, and taken to a cotton gin.

Mechanical cotton strippers remove open and unopened bolls, along with burs, leaves, and stems from cotton plants, leaving only bare branches. Tractor-mounted, tractor-pulled, or self-propelled strippers require only 1 operator. They harvest from 1 to 4 rows of cotton at speeds of 1.8 to 2.7 m/s (4.0 - 6.0 mph). After the cotton is stripped, it enters a conveying system that carries it from the stripping unit to an elevator. Most conveyers utilize either augers or a series of rotating spike-toothed cylinders to move the cotton, accomplishing some cleaning by moving the cotton over perforated, slotted, or wire mesh screen. Dry plant material (burs, stems, and leaves) is crushed and dropped through openings to the ground. Blown air is sometimes used to assist cleaning.

9.3.1.2 Emissions And Controls

Emission factors for the drifting of major chemicals applied to cotton were compiled from literature and reported in Reference 1. In addition, drift losses from arsenic acid spraying were developed by field testing. Two off-target collection stations, with 6 air samplers each, were located downwind from the ground spraying operations. The measured concentration was applied to an infinite line source atmosphere diffusion model (in reverse) to calculate the drift emission rate. This was in turn used for the final emission factor calculation. The emissions occur from July to October, preceding by 2 weeks the period of harvest in each cotton producing region. The drift emission factor for arsenic acid is 8 times lower than previously estimated, since Reference 1 used a ground rig rather than an airplane, and because of the low volatility of arsenic acid. Various methods of controlling drop size, proper timing of application, and modification of equipment are practices that can reduce drift hazards. Fluid additives have been used that increase the viscosity of the spray formulation, and thus decrease the number of fine droplets (<100 micrometers [μ m]). Spray nozzle design and orientation also control the droplet size spectrum. Drift emission factors for the defoliation or desiccation of cotton are listed in Table 9.3.1-1. Factors are expressed in units of grams per kilogram (g/kg) and pounds per ton (lb/ton).

Table 9.3.1-1 (Metric And English Units). EMISSION FACTORS FOR DEFOLIATION OR DESICCATION OF COTTON^a

	Emission Factor ^b			
Pollutant	g/kg	lb/ton		
Sodium chlorate	10.0	20.0		
DEF ^{®c}	10.0	20.0		
Arsenic acid	6.1	12.2		
Paraquat	10.0	20.0		

EMISSION FACTOR RATING: C

^a Reference 1.

^b Factor is in terms of quantity of drift per quantity applied.

^c Pesticide trade name.

Three unit operations are involved in mechanical harvesting of cotton: harvesting, trailer loading (basket dumping), and transport of trailers in the field. Emissions from these operations are in the form of solid particulates. Particulate emissions ($<7 \mu m$ mean aerodynamic diameter) from these operations were developed in Reference 2. The particulates are composed mainly of raw cotton dust and solid dust, which contains free silica. Minor emissions include small quantities of pesticide, defoliant, and desiccant residues that are present in the emitted particulates. Dust concentrations from harvesting were measured by following each harvesting machine through the field at a constant distance directly downwind from the machine while staying in the visible plume centerline. The procedure for trailer loading was the same, but since the trailer is stationary while being loaded, it was necessary only to stand a fixed distance directly downwind from the trailer while the plume or puff passed over. Readings were taken upwind of all field activity to get background concentrations. Particulate emission factors for the principal types of cotton harvesting operations in the U.S. are shown in Table 9.3.1-2. The factors are based on average machine speed of 1.34 m/s (3.0 mph) for pickers, and 2.25 m/s (5.03 mph) for strippers, on a basket capacity of 109 kg (240 lb), on a trailer capacity of 6 baskets, on a lint cotton yield of 63.0 megagrams per square kilometer (Mg/km²) (1.17 bales/acre) for pickers and 41.2 Mg/km² (0.77 bale/acre) for strippers, and on a transport speed of 4.47 m/s (10.0 mph). Factors are expressed in units of kg/km² and pounds per square mile (lb/mi²). Analysis of particulate samples showed average free silica content of 7.9 percent for mechanical cotton picking and 2.3 percent for mechanical cotton stripping. Estimated maximum percentages for pesticides, defoliants, and desiccants from harvesting are also noted in Table 9.3.1-2. No current cotton harvesting equipment or practices provide for control of emissions. In fact,

EMISSION FACTORS

Table 9.3.1-2 (Metric And English Units). PARTICULATE EMISSION FACTORS^a FOR COTTON HARVESTING OPERATIONS

	Harve	esting	Trailer Loading		Transport		Total	
Type of Harvester	kg/km²	lb/mi ²	kg/km ²	lb/mi ²	kg/km ²	lb/mi ²	kg/km ²	lb/mi ²
Picker ^b Two-row, with basket	0.46	2.6	0.070	0.40	0.43	2.5	0.96	5.4
Stripper ^c					1			
Two-row, pulled trailer	7.4	42	NA	NA	0.28	1.6	7.7	44
Two-row, with basket	2.3	13	0.092	0.52	0.28	1.6	2.7	15
Four-row, with basket	2.3	13	0.092	0.52	0.28	1.6	2.7	15
Weighted average ^d	4.3	24	0.056	0.32	0.28	1.6	4.6	26

EMISSION FACTOR RATING: C

^a Emission factors are from Reference 2 for particulate of $<7 \mu m$ mean aerodynamic diameter. NA = not applicable.

^b Free silica content is 7.9% maximum content of pesticides and defoliants is 0.02%.

^c Free silica content is 2.3%; maximum content of pesticides and desiccants is 0.2%.

^d The weighted average stripping factors are based on estimates that 2% of all strippers are 4-row models with baskets and, of the remainder, 40% are 2-row models pulling trailers and 60% are 2-row models with mounted baskets.

equipment design and operating practices tend to maximize emissions. Preharvest treatment (defoliation and desiccation) and harvest practices are timed to minimize moisture and trash content, so they also tend to maximize emissions. Soil dust emissions from field transport can be reduced by lowering vehicle speed.

References For Section 9.3.1

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9.3.2 Grain Harvesting

9.3.2.1 General¹

Harvesting of grain refers to the activities performed to obtain the cereal kernels of the plant for grain, or the entire plant for forage and/or silage uses. These activities are accomplished by machines that cut, thresh, screen, clean, bind, pick, and shell the crops in the field. Harvesting also includes loading harvested crops into trucks and transporting crops in the grain field.

Crops harvested for their cereal kernels are cut as close as possible to the inflorescence (the flowering portion containing the kernels). This portion is threshed, screened, and cleaned to separate the kernels. The grain is stored in the harvest machine while the remainder of the plant is discharged back onto the field.

Combines perform all of the above activities in 1 operation. Binder machines only cut the grain plants and tie them into bundles, or leave them in a row in the field (called a windrow). The bundles are allowed to dry for threshing later by a combine with a pickup attachment.

Corn harvesting requires the only exception to the above procedures. Corn is harvested by mechanical pickers, picker/shellers, and combines with corn head attachments. These machines cut and husk the ears from the standing stalk. The sheller unit also removes the kernels from the ear. After husking, a binder is sometimes used to bundle entire plants into piles (called shocks) to dry.

For forage and/or silage, mowers, crushers, windrowers, field choppers, binders, and similar cutting machines are used to harvest grasses, stalks, and cereal kernels. These machines cut the plants as close to the ground as possible and leave them in a windrow. The plants are later picked up and tied by a baler.

Harvested crops are loaded onto trucks in the field. Grain kernels are loaded through a spout from the combine, and forage and silage bales are manually or mechanically placed in the trucks. The harvested crop is then transported from the field to a storage facility.

9.3.2.2 Emissions And Controls¹

Emissions are generated by 3 grain harvesting operations: (1) crop handling by the harvest machine, (2) loading of the harvested crop into trucks, and (3) transport by trucks in the field. Particulate matter, composed of soil dust and plant tissue fragments (chaff), may be entrained by wind. Particulate emissions from these operations (<7 micrometers $[\mu m]$ mean aerodynamic diameter) were developed in Reference 1. For this study, collection stations with air samplers were located downwind (leeward) from the harvesting operations, and dust concentrations were measured at the visible plume centerline and at a constant distance behind the combines. For product loading, since the trailer is stationary while being loaded, it was necessary only to take measurements a fixed distance downwind from the trailer while the plume or puff passed over. The concentration measured for harvesting and loading was applied to a point source atmospheric diffusion model to calculate the source emission rate. For field transport, the air samplers were again placed a fixed distance downwind from the path of the truck, but this time the concentration measured was applied to a line source diffusion model. Readings taken upwind of all field activity gave background concentrations. Particulate emission factors for wheat and sorghum harvesting operations are shown in Table 9.3.2-1.

Table 9.3.2 (Metric And English Units). EMISSION RATES/FACTORS FROM GRAIN HARVESTING^a

	Emission Rate ^b				Emission Factor ^c			
	Wheat		Sorghum		Wheat		Sorghum	
Operation	mg/s	lb/hr	mg/s	lb/hr	g/km ²	lb/mi ²	g/km ²	lb/mi ²
Harvest machine	3.4	0.027	23.0	0.18	170.0	0.96	1110.0	6.5
Truck loading	1.8	0.014	1.8	0.014	12.0	0.07	22.0	0.13
Field transport	47.0	0.37	47.0	0.37	110.0	0.65	200.0	1.2

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^a Reference 1.

^b Assumptions from References 1 are an average combine speed of 3.36 meters per second, combine swath width of 6.07 meters, and a field transport speed of 4.48 meters per second.

^c In addition to footnote b, assumptions are a truck loading time of 6 minutes, a truck capacity of 0.052 km² for wheat and 0.029 km² for sorghum, and a filled truck travel time of 125 seconds per load.

Emission rates are expressed in units of milligrams per second (mg/s) and pounds per hour (lb/hr); factors are expressed in units of grams per square kilometer (g/km²) and pounds per square mile (lb/mi²).

There are no control techniques specifically implemented for the reduction of air pollution emissions from grain harvesting. However, several practices and occurrences do affect emission rates and concentration. The use of terraces, contouring, and stripcropping to inhibit soil erosion will suppress the entrainment of harvested crop fragments in the wind. Shelterbelts, positioned perpendicular to the prevailing wind, will lower emissions by reducing the wind velocity across the field. By minimizing tillage and avoiding residue burning, the soil will remain consolidated and less prone to disturbance from transport activities.

Reference For Section 9.3.2

1. R. A. Wachten and T. R. Blackwood, Source Assessment: Harvesting Of Grain-State Of The Art, EPA-600/2-79-107f, U. S. Environmental Protection Agency, Cincinnati, OH, July 1977.

9.3.3 Rice Harvesting

[Work In Progress]

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9.3.4 Cane Sugar Harvesting

[Work In Progress]

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9.4 Livestock And Poultry Feed Operations

- 9.4.1 Cattle Feedlots
- 9.4.2 Swine Feedlots
- 9.4.3 Poultry Houses
- 9.4.4 Dairy Farms

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9.4.1 Cattle Feedlots

[Work In Progress]

9.4.2 Swine Feedlots

[Work In Progress]

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9.4.3 Poultry Houses

[Work In Progress]

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9.4.4 Dairy Farms

[Work In Progress]

9.5 Animal And Meat Products Preparation

- 9.5.1 Meat Packing Plants
- 9.5.2 Meat Smokehouses
- 9.5.3 Meat Rendering Plants
- 9.5.4 Manure Processing
- 9.5.5 Poultry Slaughtering

9.5.1 Meat Packing Plants

9.5.1.1 General¹⁻²

The meat packing industry is made up of establishments primarily engaged in the slaughtering, for their own account or on a contract basis for the trade, of cattle, hogs, sheep, lambs, calves, and vealers for meat to be sold or to be used on the same premises in canning, cooking, curing, and freezing, and in making sausage, lard, and other products. Also included in this industry are establishments primarily engaged in slaughtering horses for human consumption.

9.5.1.2 Process Description³⁻⁷

The following sections describe the operations involved in beef processing, pork processing, and other meat processing. Figure 9.5.1-1 provides a generic process flow diagram for meat packing operations.

9.5.1.2.1 Beef Processing³⁻⁷ -

Animals are delivered from the market or farm to the meat plant and are placed in holding areas. These holding areas should have adequate facilities for the inspection of livestock, including walkways over pens, crushes, and other facilities. Sick animals and those unfit for human consumption are identified and removed from the normal processing flow. Plants should have separate isolation and holding pens for these animals, and may have separate processing facilities. The live beef animals are weighed prior to processing so that yield can be accurately determined.

The animals are led from the holding area to the immobilization, or stunning, area where they are rendered unconscious. Stunning of cattle in the U.S. is usually carried out by means of a penetrating or nonpenetrating captive bolt pistol. Livestock for Kosher markets are not immobilized prior to exsanguination.

The anesthetized animals are then shackled and hoisted, hind quarters up, for exsanguination (sticking), which should be carried out as soon as possible after stunning. In cattle, exsanguination is effected by severing the carotid artery and the jugular vein. Blood is collected through a special floor drain or collected in large funneled vats or barrels and sent to a rendering facility for further processing. More information on rendering operations can be found in AP-42 Section 9.5.3, Meat Rendering Plants. Blood can be used in human food only if it is kept completely sterile by removal from the animals through tubes or syringes.

In some plants, electrical stimulation (ES) is applied to the carcasses to improve lean color, firmness, texture, and marbling score; to improve bleeding of carcasses; and to make removal of the hides easier. Electrical stimulation also permits rapid chilling by hastening the onset of rigor before temperatures drop to the cold shortening range. If muscles reach temperatures below 15° to 16° C (59° to 61° F) before they have attained rigor, a contraction known as cold shortening occurs, which results in much less tender meat. In some cases ES is applied to control the fall of pH value. Meat with a low pH value will be pale, soft, and exudative (PSE meat). Meat with a high pH value may be dark, firm, and dry (DFD meat). It has been claimed that ES enhances tenderness, primarily through the hastening of the onset of rigor and prevention of cold shortening. Both high-voltage (>500 volts) and low-voltage (30 to 90 volts) ES systems can be used.



After exsanguination, the actual "dressing", or cleaning, of the carcasses begins. The first step is to separate the esophagus from the trachea, called "rodding the weasand". Alternatively, this can be done after the chest cavity has been opened. This separation aids in evisceration. After separation, a knot is made in the esophagus, or a band is put around it to prevent the contents of the rumen (first stomach) from spilling and contaminating the carcass.

Next, the skin is removed from the head, and the head is removed from the carcass by cutting through the Adam's apple and the atlas joint (heading). The fore and hind feet are then removed to prevent contamination of the carcass with manure and dirt dropped from the hooves (shanking or legging). Each of the legs is then skinned.

The hide is then opened down the middle of the ventral side over the entire length of the carcass. The hide is removed from the middle down over the sides (siding). Air or electrically powered rotary skinning knives are often used to make skinning easier. Care is taken to avoid cutting or scoring the hide, as this decreases its value for leather.

After siding, the carcass is opened (opening). First, a cut is made through the fat and muscle at the center of the brisket with a knife. Then a saw is used to cut through the sternum. The hind quarters are separated with a saw or knife. The tail is skinned and then removed two joints from the body. After removing the tail, the hide is completely removed (backing). Hides are collected, intermediate preserving operations performed, and the preserved hides sent to tanners for processing into leather. More information on leather tanning processes can be found in AP-42 Section 9.15, Leather Tanning.

After the hide is removed, the carcass is eviscerated. With a knife, the abdomen of the carcass is opened from top to bottom. The fat and membranes that hold the intestines and bladder in place are loosened, and the ureters connecting the bladder and the kidneys are cut. The liver is removed for inspection. The previously loosened esophagus is pulled up through the diaphragm to allow the abdominal organs to fall freely into an inspection cart. The diaphragm membrane is cut and the thoracic organs are removed.

A handsaw or electric saw is used to cut through the exact center of the backbone to split the beef carcass into sides (halving or splitting). Inedible material is collected and sent to a rendering plant for further processing. More information on meat rendering processes can be found in AP-42 Section 9.5.3, Meat Rendering Plants.

After dressing, the carcasses are washed to remove any remaining blood or bone dust. The carcasses may also be physically or chemically decontaminated. The simplest physical decontamination method involves spraying the carcass with high pressure hot water or steam. A variety of chemical decontaminants may be used as well; acetic and lactic acids are the most widely used and appear to be the most effective. In addition, the following may be used: the organic acids, adipic, ascorbic, citric, fumaric, malic, propionic, and sorbic; aqueous solutions of chlorine, hydrogen peroxide, beta-propiolactone, and glutaraldehyde; and inorganic acids, including hydrochloric and phosphoric.

After the carcasses are dressed and washed, they are weighed and chilled. A thorough chilling during the first 24 hours is essential, otherwise the carcasses may sour. Air chillers are most common for beef sides. A desirable temperature for chilling warm beef carcasses is $0^{\circ}C$ ($32^{\circ}F$). Because a group of warm carcasses will raise the temperature of a chill room considerably, it is good practice to lower the temperature of the room to 5° below freezing ($-3^{\circ}C$ [$27^{\circ}F$]) before the carcasses are moved in. Temperatures more severe than this can cause cold shortening, an intense shortening of muscle fibers, which brings about toughening.

Beef undergoes maturation and should be held for at least a week (preferably longer) at $0^{\circ}C$ (32°F) before butchery into retail joints. In the past, sides remained intact up to the point of butchery, but it is now common practice to break down the carcasses into primal joints (wholesale cuts), which are then vacuum packed. Preparation of primal joints in packing plants reduces refrigeration and transport costs, and is a convenient pre-packing operation for retailers.

Some meat products are smoked or cured prior to market. More information on smoking and curing processes can be found in AP-42 Section 9.5.2, Meat Smokehouses.

In the manufacture of frankfurters (hot dogs) and other beef sausages, a mix of ground lean meat and ground fat are blended together; then spices, preservatives, extenders, and other ingredients are blended with the mixture. The mix is transferred to the hopper of the filling machine and fed to a nozzle by a piston pump. The casing, either natural or artificial, is filled from the nozzle on a continuous basis and linked, either manually or mechanically, to form a string of individual frankfurters or sausages.

9.5.1.2.2 Pork Processing³⁻⁷ -

Animals are delivered from the market or farm to the meat plant and are placed in holding areas. These holding areas should have adequate facilities for the inspection of livestock, including walkways over pens, crushes, and other facilities. Sick animals and those unfit for human consumption are identified and removed from the normal processing flow. Plants should have separate isolation and holding pens for these animals, and may have separate processing facilities. The live animals are weighed prior to processing so that yield can be accurately determined.

Hogs must be rendered completely unconscious, in a state of surgical anesthesia, prior to being shackled and hoisted for exsanguination. In large commercial operations, a series of chutes and restrainer conveyers move the hogs into position for stunning. The V restrainer/conveyer, or similar system, is used in most large hog processing operations. Hogs must be stunned with a federally acceptable device (mechanical, chemical, or electrical). Mechanical stunning involves the use of a compression bolt with either a mushroom head or a penetrating head. The force may be provided with compressed air or with a cartridge. Mechanical stunning is largely confined to smaller operations. Chemical stunning involves the use of CO_2 , which reduces blood oxygen levels, causing the animals to become anesthetized. Electrical stunning involves the use of an electric current and two electrodes placed on the head.

Deep stunning, which was approved by the U.S. Department of Agriculture, Food and Safety Inspection Service in 1985, requires more amperage and voltage and a third electrode attached to the back or a foot. Stunning causes the heart to stop beating (cardiac arrest). The stunned animals undergo exsanguination (sticking) and blood collection in the same manner as described for cattle.

Hog carcasses, unlike cattle carcasses, generally are not skinned after exsanguination. Instead, the carcasses are dropped into scalding water which loosens the hair for subsequent removal. The carcasses should be kept under water and continually moved and turned for uniform scalding. In large plants, carcasses enter the scalding tub and are carried through the tub by a conveyer moving at the proper speed to allow the proper scalding time. During the hard-hair season (September-November), the water temperature should be 59° to 60° C (139° to 140° F) and the immersion period 4 to 4-1/2 minutes, while in the easy-hair season (February-March), a temperature of 58° C (136° F) for 4 minutes is preferable. In small plants without automation, hair condition is checked periodically during the scalding period. Some plants use an alternative to scalding that involves passing the carcass through gas flames to singe the hair. The hair is then removed by rotating brushes and water sprays, and the carcass is rinsed.

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Various dehairing machines, sometimes called "polishers", are manufactured to remove hair from the scalded pork carcasses. The dehairing process is begun with a dehairing machine, which uses one or more cylinders with metal tipped rubber beaters to scour the outside of the carcasses. Hot water (60°C [140°F]) is sprayed on the carcasses as they pass through the dehairer moving toward the discharge end. The carcasses are removed from this machine, hand scraped, then hoisted again, hind quarters up. The carcasses are hand-scraped again from the top (hind quarters) down. Any remaining hairs can be removed by singeing with a propane or similar torch. Once the remaining hairs have been singed, the carcasses are scraped a final time and washed thoroughly from the hind feet to the head. Some plants pass the carcasses through a singeing machine, which singes any remaining hairs from the carcasses.

At one time, it was popular to dip dehaired carcasses into a hot solution $(121^{\circ} \text{ to } 149^{\circ}\text{C} [250^{\circ} \text{ to } 300^{\circ}\text{F}])$ of rosin and cottonseed oil for a period of six to eight seconds. When the rosin coating plasticized after cooling, it was stripped by pull-rolling it down the carcass, taking with it the remaining hair, stubble, and roots. However, in recent years, many packers have discontinued its use, turning instead to mechanical brushes and torches to completely clean dehaired pork carcasses.

In some plants, hogs are skinned after exsanguination. The head and belly of the carcass are handskinned, and the legs are either hand-skinned or removed. Then the carcass is hoisted, hind quarters up, and placed under tension. A second hoist is connected to the loose head and leg skin and tightened to pull the remaining skin from the carcass. The removed pigskins are trimmed, salted, folded, and stored in 50-gallon drums.

After scalding and dehairing, singeing, or skinning, the head is severed from the backbone at the atlas joint, and the cut is continued through the windpipe and esophagus. The head is inspected, the tongue is dropped, and the head is removed from the carcass. The head is cleaned, washed, and an inspection stamp is applied.

Following heading, the carcass is eviscerated. The hams are separated, the sternum is split, the ventral side is opened down the entire length of the carcass, and the abdominal organs are removed. The thoracic organs are then freed. All of the internal organs are inspected, those intended for human consumption are separated, and the remainder are discarded into a barrel to be shipped to the rendering plant. As mentioned previously, more information on meat rendering can be found in AP-42 Section 9.5.3, Meat Rendering Plants.

After evisceration, the carcass is split precisely in half. Glands and blood clots in the neck region are removed, the leaf fat and kidneys are removed, and the hams are faced (a strip of skin and fat is removed to improve appearance).

The carcass is then washed from the top down to remove any bone dust, blood, or bacterial contamination. A mild salt solution (0.1 M KCl) weakens bacterial attachment to the carcass and makes the bacteria more susceptible to the sanitization procedure, especially if the sanitizing solution is applied promptly. Dilute organic acids (2 percent lactic acid and 3 percent acetic acid) are good sanitizers. In large operations, carcass washing is automated. As the carcass passes through booths on the slaughter line, the proper solutions are applied at the most effective pressure.

After washing and sanitizing, the carcass is inspected one final time, weighed, and the inspection stamp is applied to each wholesale cut. The carcass is then placed in a cooler at 0° to $1^{\circ}C$ (32° to $34^{\circ}F$) with air velocity typically 5 to 15 mph, equating to $-5^{\circ}C$ ($23^{\circ}F$) wind chill, for a 24-hour chill period. For thorough chilling, the inside temperature of the ham should reach at least $3^{\circ}C$ ($37^{\circ}F$). With accelerated (hot) processing, the carcass may be held (tempered) at an intermediate temperature of $16^{\circ}C$ ($60^{\circ}F$) for several

hours, or be boned immediately. When large numbers of warm carcasses are handled, the chill room is normally precooled to a temperature several degrees below freezing $-3^{\circ}C$ (27°F), bringing the wind chill to $-9^{\circ}C$ (16°F) to compensate for the heat from the carcasses.

Spray chilling is permitted by the U.S.D.A. to reduce cooler shrink. Spray chilling solutions may contain up to 5 ppm available chlorine, which acts a sanitizer. At least one plant sends carcasses directly from the kill floor through a freezer, to produce a brightly colored pork with reduced carcass shrink. Following cooling, pork carcasses are often divided into deboned primal joints for distribution. The primal joints may be vacuum packed. To manufacture pork sausages, ground lean meat and ground fat are blended together and processed in the same manner as that described for beef sausages in Section 9.5.1.2.1.

9.5.1.2.3 Other Meat Processing -

Other meats undergo processes similar to those described above for beef and pork processing. These other meats include veal, lamb, mutton, goat, horse (generally for export), and farm-raised large game animals.

9.5.1.3 Emissions And Controls

No emission data quantifying VOC, HAP, or PM emissions from the meat packing industry were identified during the development of this report. However, engineering judgment and comparison of meat packing plant processes with similar processes in other industries may provide an estimation of the types of emissions that might be expected from meat packing plant operations.

Animal holding areas, feed storage, singeing operations, and other heat sources (including boilers) may be sources of PM and PM-10 emissions. Carbon dioxide stunning operations may be sources of CO_2 emissions. Animal holding areas, scalding tanks, singeing operations, rosin dipping (where still used), sanitizing operations, wastewater systems, and heat sources may be sources of VOC, HAP, and other criteria pollutant emissions.

Potential emissions from boilers are addressed in AP-42 Sections 1.1 through 1.4 (Combustion). Meat smokehouses, meat rendering operations, and leather tanning may be sources of air pollutant emissions, but these sources are included in other sections of AP-42 and are not addressed in this section.

A number of VOC and particulate emission control techniques are potentially available to the meat packing industry. These options include the traditional approaches of wet scrubbers, dry sorbants, and cyclones. Other options include condensation and chemical reaction. No information is available for the actual controls used at meat packing plants. The controls presented in this section are ones that theoretically could be used. The specific type of control device or combination of devices would vary from facility to facility depending upon the particular nature of the emissions and the pollutant loading in the gas stream. The VOC emissions from meat packing operations are likely to be very low and associated with a high moisture content.

Control of VOC from a gas stream can be accomplished using one of several techniques, but the most common methods are absorption, adsorption, and afterburners. Absorptive methods encompass all types of wet scrubbers using aqueous solutions to absorb the VOC. The most common scrubber systems are packed columns or beds, plate columns, spray towers, or other types of towers. Most scrubber systems require a mist eliminator downstream of the scrubber.

Gas adsorption is a relatively expensive technique and may not be applicable to a wide variety of pollutants. Adsorptive methods usually include one of four main adsorbents: activated carbon, activated

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alumina, silica gel, or molecular sieves. Of these four, activated carbon is the most widely used for VOC control, and the remaining three are used for applications other than pollution control.

Afterburners, or thermal incinerators, are add-on combustion control devices in which VOC's are oxidized to CO_2 , water, sulfur oxides, and nitrogen oxides. The destruction efficiency of an afterburner is primarily a function of the operating temperature and residence time at that temperature. A temperature above 816°C (1,500°F) will destroy most organic vapors and aerosols.

Particulate control commonly employs methods such as venturi scrubbers, dry cyclones, wet or dry electrostatic precipitators (ESPs), or dry filter systems. The most common controls are likely to be the venturi scrubbers or dry cyclones. Wet or dry ESPs are used depending upon the particulate loading of the gas stream.

Condensation methods and scrubbing by chemical reaction may be applicable techniques depending upon the type of emissions. Condensation methods may be either direct contact or indirect contact. The shell and tube indirect method is the most common technique. Chemical reactive scrubbing may be used for odor control in selective applications.

References for Section 9.5.1

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- 2. USDA, National Agricultural Statistics Service, Agricultural Statistics Board, 1995 Livestock Slaughter Annual Summary, March 14, 1996.
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9.5.2 Meat Smokehouses

9.5.2.1 General^{1-3,7-9}

Meat smokehouses are used to add flavor, color, and aroma to various meats, including pork, beef, poultry, and fish. Smokehouses were at one time used to smoke food for preservation, but refrigeration systems have effectively eliminated this use.

Four operations are typically involved in the production of smoked meat: (1) tempering or drying, (2) smoking, (3) cooking, and (4) chilling. However, not all smoked foods are cooked, thus eliminating the cooking and chilling processes from some operations. Important process parameters include cooking/smoking time, smoke generation temperature, humidity, smoke density, type of wood or liquid smoke, and product type.

The two types of smokehouses that are almost exclusively used are batch and continuous smokehouses. Figures 9.5.2-1 and 9.5.2-2 show typical batch and continuous smokehouses, respectively. Both types of systems circulate air at the desired process conditions (temperature, humidity, and smoke density) over the surface of the meat. In batch smokehouses, the meat is placed on stationary racks for the entire smoking process. In continuous smokehouses, the meat is hung on sticks or hangers and then conveyed through the various zones (smoking, heating, and chilling) within the smokehouse. Following processing in the smokehouse, the product is packaged and stored for shipment.

Several methods are used to produce the smoke used in smokehouses. The most common method is to pyrolyze hardwood chips or sawdust using smoke generators. In a typical smoke generator, hardwood chips or sawdust are fed onto a gas- or electrically-heated metal surface at 350° to 400° C (662° to 752° F). Smoke is then ducted by a smoke tube into the air recirculation system in the smokehouse. Smoke produced by this process is called natural smoke.

Liquid smoke (or artificial smoke), which is a washed and concentrated natural smoke, is also used in smokehouses. This type of smoke (as a fine aerosol) can be introduced into a smokehouse through the air recirculation system, can be mixed or injected into the meat, or can be applied by drenching, spraying, or dipping.

9.5.2.2 Emissions And Controls^{1-2,4}

Particulate matter (PM), carbon monoxide (CO), volatile organic compounds (VOC), polycyclic aromatic hydrocarbons (PAH), organic acids, acrolein, acetaldehyde, formaldehyde, and nitrogen oxides have been identified as pollutants associated with meat smokehouses. The primary source of these pollutants is the smoke used in the smokehouses. Studies cited in Reference 1 show that almost all PM from smoke has an aerodynamic diameter of less than 2.0 micrometers (μ m). Acetic acid has been identified as the most prevalent organic acid present in smoke, followed by formic, propionic, butyric, and other acids. Also, acetaldehyde concentrations have been shown to be about five times greater than formaldehyde concentrations in smoke. Heating zones in continuous smokehouses (and the cooking cycle in batch smokehouses) are a source of odor that includes small amounts of VOC. The VOC are a result of the volatilization of organic compounds contained in the meat or the smoke previously applied to the meat. Heating zones are typically heated with ambient air that is passed over electrically-heated or steam-heated coils (steam from boilers used elsewhere at the facility). Therefore, heating zones are not a source of combustion products. Factors that may

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Figure 9.5.2-1. Typical batch smokehouse.¹ (Source Classification Code in parentheses.)



Figure 9.5.2-2. Typical continuous smokehouse.¹ (Source Classification Code in parentheses.)

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effect smokehouse emissions include the amount and type of wood or liquid smoke used, the type of meat processed, the processing time, humidity, and the temperature maintained in the smoke generators.

Control technologies used at meat smokehouses include afterburners, wet scrubbers, and modular electrostatic precipitators (ESP). Emissions can also be reduced by controlling important process parameters. An example of this type of process control is maintaining a temperature not higher than about 400°C (752°F) in the smoke generator, to minimize the formation of PAH.

Afterburners are an effective control technology for PM, organic gases, and CO from smokehouses, but energy requirements may be costly for continuous smokehouse operations. Also, the additional air pollution resulting from afterburner fuel combustion makes afterburners a less desirable option for controlling smokehouse emissions.

Wet scrubbers are another effective control technology for both PM and gaseous emissions. Different types of scrubbers used include mist scrubbers, packed bed scrubbers, and vortex scrubbers. Mist scrubbers introduce a water fog into a chamber, and exhaust gases are then fed into the chamber and are absorbed. Packed bed scrubbers introduce the exhaust gases into a wetted column containing an inert packing material in which liquid/gas contact occurs. Vortex scrubbers use a whirling flow pattern to shear water into droplets, which then contact the exhaust gases. Limited test data (from Reference 4) show a vortex scrubber (followed by a demister) achieving about 51 percent formaldehyde removal, 85 percent total organic compound removal, 39 percent acetic acid removal, and 69 percent PM removal. Particulate matter removal efficiencies for scrubbers can be increased through the use of surfactants, which may enhance the capture of smoke particles that do not combine with the scrubber water.

Electrostatic precipitators are effective for controlling PM emissions. Combined control technologies, such as a wet scrubber for gaseous emission control followed by an ESP for PM removal, may also be used to control emissions from smokehouses.

Smokehouse control devices are operated during the smoking cycle and are sometimes bypassed during the cooking and cooling cycles. Continuous smokehouses may include separate vents for exhaust streams from the different zones, thus minimizing the air flow through the control device.

The average emission factors for meat smokehouses are shown in Tables 9.5.2-1 and 9.5.2-2. These emission factors are presented in units of mass of pollutant emitted per mass of wood used to generate smoke. Normally, emission factors are based on either units of raw material or units of product. In this industry, the amount of smoke flavor applied to the meats varies; consequently the emissions are dependent on the quantity of wood (or liquid smoke) used, rather than the quantity of meat processed. The emission factors presented in Tables 9.5.2-1 and 9.5.2-2 were developed using data from only two facilities and, consequently, may not be representative of the entire industry.

Table 9.5.2-1. EMISSION FACTORS FOR BATCH AND CONTINUOUS MEAT SMOKEHOUSES^a

EMISSION FACTOR RATING: D

	Filterable PM		Condensible PM			Total PM	
Process	PM	PM-10	Inorganic	Organic	Total	PM	PM-10
Batch smokehouse, smoking cycle ^b (SCC 3-02-013-02)	23	ND ^c	11	19	30	53	ND°
Continuous smokehouse, smoke zone ^d (SCC 3-02-013-04)	66	ND ^c	36	39	75	140	ND ^c
Continuous smokehouse, smoke zone, with vortex wet scrubber and demister ^d (SCC 3-02-013-04)	13	ND ^c	9.8	6.0	16	29	ND ^c

^a Emission factor units are lb/ton of wood or sawdust used. ND = no data available. SCC = Source Classification Code.

^b Reference 5.

^c Although data are not directly available, Reference 1 states that all PM from smoke is less than 2 micrometers in aerodynamic diameter.

^d References 4-6.

Table 9.5.2-2. EMISSION FACTORS FOR BATCH AND
CONTINUOUS MEAT SMOKEHOUSES^a

Process	VOC	EMISSION FACTOR RATING	Formaldehyde	EMISSION FACTOR RATING	Acetic Acid	EMISSION FACTOR RATING
Batch smokehouse, smoking cycle ^b (SCC 3-02-013-02)	44	D	ND	NA	ND	NA
Batch smokehouse, cooking cycle (SCC 3-02-013-03)	ND	NA	ND	NA	ND	NA
Continuous smokehouse, smoke zone ^c (SCC 3-02-013-04)	17	D	1.3	Е	4.5	E
Continuous smokehouse, smoke zone, with vortex wet scrubber and demister ^d (SCC 3-02-013-04)	4.4	Е	0.62	Е	2.8	Е
Continuous smokehouse, heat zone (SCC 3-02-013-05)	ND	NA	ND	NA	ND	NA

^a Emission factor units are lb/ton of wood or sawdust used, unless noted. ND = no data available. NA = not applicable. SCC = Source Classification Code.

^b Reference 5. VOC, measured as methane.

^c References 5-6. VOC, measured as methane.

^d Reference 4. VOC, measured as methane. VOCs were measured on a gas chromatograph calibrated against acetaldehyde, and the results were converted to a methane basis.

References For Section 9.5.2

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9.5.3 Meat Rendering Plants

9.5.3.1 General¹

Meat rendering plants process animal by-product materials for the production of tallow, grease, and high-protein meat and bone meal. Plants that operate in conjunction with animal slaughterhouses or poultry processing plants are called integrated rendering plants. Plants that collect their raw materials from a variety of offsite sources are called independent rendering plants. Independent plants obtain animal by-product materials, including grease, blood, feathers, offal, and entire animal carcasses, from the following sources: butcher shops, supermarkets, restaurants, fast-food chains, poultry processors, slaughterhouses, farms, ranches, feedlots, and animal shelters.

The two types of animal rendering processes are edible and inedible rendering. Edible rendering plants process fatty animal tissue into edible fats and proteins. The plants are normally operated in conjunction with meat packing plants under U. S. Department of Agriculture, Food Safety and Inspection Services (USDA/FSIS) inspection and processing standards. Inedible rendering plants are operated by independent renderers or are part of integrated rendering operations. These plants produce inedible tallow and grease, which are used in livestock and poultry feed, soap, and production of fatty-acids.

9.5.3.2 Process Description¹⁻³

Raw Materials -

Integrated rendering plants normally process only one type of raw material, whereas independent rendering plants often handle several raw materials that require either multiple rendering systems or significant modifications in the operating conditions for a single system.

Edible Rendering -

A typical edible rendering process is shown in Figure 9.5.3-1. Fat trimmings, usually consisting of 14 to 16 percent fat, 60 to 64 percent moisture, and 22 to 24 percent protein, are ground and then belt conveyed to a melt tank. The melt tank heats the materials to about $43 \,^{\circ}C$ (110°F), and the melted fatty tissue is pumped to a disintegrator, which ruptures the fat cells. The proteinaceous solids are separated from the melted fat and water by a centrifuge. The melted fat and water are then heated with steam to about $93 \,^{\circ}C$ (200°F) by a shell and tube heat exchanger. A second-stage centrifuge then separates the edible fat from the water, which also contains any remaining protein fines. The water is discharged as sludge, and the "polished" fat is pumped to storage. Throughout the process, direct heat contact with the edible fat is minimal and no cooking vapors are emitted. For this reason, no emission points are designated in Figure 9.5.3-1.

Inedible Rendering -

There are two processes for inedible rendering: the wet process and the dry process. Wet rendering is a process that separates fat from raw material by boiling in water. The process involves addition of water to the raw material and the use of live steam to cook the raw material and accomplish separation of the fat. Dry rendering is a batch or continuous process that dehydrates raw material in order to release fat. Following dehydration in batch or continuous cookers, the melted fat and protein solids are separated. At present, only dry rendering is used in the United States. The wet rendering process is no longer used because of the high cost of energy and of an adverse effect

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on the fat quality. Table 9.5.3-1 shows the fat, protein, and moisture contents for several raw materials processed by inedible rendering plants.

Batch Rendering Process —

In the batch process, the raw material from the receiving bin is screw conveyed to a crusher where it is reduced to 2.5 to 5 centimeters (cm) (1 to 2 inches [in.]) in size to improve cooking efficiency. Cooking normally requires 1.5 to 2.5 hr, but adjustments in the cooking time and temperature may be required to process the various materials. A typical batch cooker is a horizontal, cylindrical vessel equipped with a steam jacket and an agitator. To begin the cooking process the cooker is charged with raw material, and the material is heated to a final temperature ranging from 121° to 135°C (250° to 275°F). Following the cooking cycle, the contents are discharged to the percolator drain pan. Vapor emissions from the cooker pass through a condenser where the water vapor is condensed and noncondensibles are emitted as VOC emissions.

The percolator drain pan contains a screen that separates the liquid fat from the protein solids. From the percolator drain pan, the protein solids, which still contain about 25 percent fat, are conveyed to the screw press. The screw press completes the separation of fat from solids, and yields protein solids that have a residual fat content of about 10 percent. These solids, called cracklings, are then ground and screened to produce protein meal. The fat from both the screw press and the percolator drain pan is pumped to the crude animal fat tank, centrifuged or filtered to remove any remaining protein solids, and stored in the animal fat storage tank.

Continuous Rendering Process -

Since the 1960, continuous rendering systems have been installed to replace batch systems at some plants. Figure 9.5.3-2 shows the basic inedible rendering process using the continuous process. The system is similar to a batch system except that a single, continuous cooker is used rather than several parallel batch cookers. A typical continuous cooker is a horizontal, steam-jacketed cylindrical vessel equipped with a mechanism that continuously moves the material horizontally through the cooker. Continuous cookers cook the material faster than batch cookers, and typically produce a higher quality fat product. From the cooker, the material is discharged to the drainer, which serves the same function as the percolator drain pan in the batch process. The remaining operations are generally the same as the batch process operations.

Current continuous systems may employ evaporators operated under vacuum to remove moisture from liquid fat obtained using a preheater and a press. In this system, liquid fat is obtained by precooking and pressing raw material and then dewatered using a heated evaporator under vacuum. The heat source for the evaporator is hot vapors from the cooker/dryer. The dewatered fat is then recombined with the solids from the press prior to entry into the cooker/dryer.

Blood Processing And Drying -

Whole blood from animal slaughterhouses, containing 16 to 18 percent total protein solids, is processed and dried to recover protein as blood meal. At the present time, less than 10 percent of the independent rendering plants in the U. S. process whole animal blood. The blood meal is a valuable ingredient in animal feed because it has a high lysine content. Continuous cookers have replaced batch cookers that were originally used in the industry because of the improved energy efficiency and product quality provided by continuous cookers. In the continuous process, whole blood is introduced into a steam-injected, inclined tubular vessel in which the blood solids coagulate. The coagulated blood solids and liquid (serum water) are then separated in a centrifuge, and the blood solids dried in either a continuous gas-fired, direct-contact ring dryer or a steam tube, rotary dryer.

Source	Tallow/Grease, wt %	Protein Solids, wt %	Moisture, wt %			
Packing house offal ^b and bone						
Steers	30-35	15-20	45-55			
Cows	10-20	20-30	50-70			
Calves	10-15	15-20	65-75			
Sheep	25-30	20-25	45-55			
Hogs	25-30	10-15	55-65			
Poultry offal	10	25	65			
Poultry feathers	None	33	67			
Dead stock (whole animals)						
Cattle	12	25	63			
Calves	10	22	68			
Sheep	22	25	53			
Hogs	30	28	42			
Butcher shop fat and bone	31	32	37			
Blood	None	16-18	82-84			
Restaurant grease	65	10	25			

Table 9.5.3-1. COMPOSITION OF RAW MATERIALS FOR INEDIBLE RENDERING^a

* Reference 1.

^b Waste parts; especially the entrails and similar parts from a butchered animal.



Protein Meal Storage Hopper

VOC Emissions

Screw Press

PM Emissions

Grinder

Protein

Fat

Protein Solids

Oversize

Drainer

Fat Tank

Screen

Poultry Feathers And Hog Hair Processing -

The raw material is introduced into a batch cooker, and is processed for 30 to 45 minutes at temperatures ranging from 138° to 149°C (280° to 300°F) and pressures ranging from (40 to 50 psig). This process converts keratin, the principal component of feathers and hog hair, into amino acids. The moist meal product, containing the amino acids, is passed either through a hot air, ring-type dryer or over steam-heated tubes to remove the moisture from the meal. If the hot air dryer is used, the dried product is separated from the exhaust by cyclone collectors. In the steam-heated tube system, fresh air is passed countercurrent to the flow of the meal to remove the moisture. The dried meal is transferred to storage. The exhaust gases are passed through controls prior to discharge to the atmosphere.

Grease Processing --

Grease from restaurants is recycled as another raw feed material processed by rendering plants. The grease is bulk loaded into vehicles, transported to the rendering plant, and discharged directly to the grease processing system. During processing, the melted grease is first screened to remove coarse solids, and then heated to about $93 \,^{\circ}C$ (200 $^{\circ}F$) in vertical processing tanks. The material is then stored in the processing tank for 36 to 48 hr to allow for gravity separation of the grease, water, and fine solids. Separation normally results in four phases: (1) solids, (2) water, (3) emulsion layer, and (4) grease product. The solids settle to the bottom and are separated from the water layer above. The emulsion is then processed through a centrifuge to remove solids and another centrifuge to remove water and any remaining fines; the grease product is skimmed off the top.

9.5.3.3 Emissions And Controls¹⁻⁵

Emissions -

Volatile organic compounds (VOCs) are the primary air pollutants emitted from rendering operations. The major constituents that have been qualitatively identified as potential emissions include organic sulfides, disulfides, C-4 to C-7 aldehydes, trimethylamine, C-4 amines, quinoline, dimethyl pyrazine, other pyrazines, and C-3 to C-6 organic acids. In addition, lesser amounts of C-4 to C-7 alcohols, ketones, aliphatic hydrocarbons, and aromatic compounds are potentially emitted. No quantitative emission data were presented. Historically, the VOCs are considered an odor nuisance in residential areas in close proximity to rendering plants, and emission controls are directed toward odor elimination. The odor detection threshold for many of these compounds is low; some as low as 1 part per billion (ppb). Of the specific constituents listed, only quinoline is classified as a hazardous air pollutant (HAP). In addition to emissions from rendering operations, VOCs may be emitted from the boilers used to generate steam for the operation.

Emissions from the edible rendering process are not considered to be significant because no cooking vapors are emitted and direct heat contact with the edible fat is minimal. Therefore, these emissions are not discussed further.

For inedible rendering operations, the primary sources of VOC emissions are the cookers and the screw press. Other sources of VOC emissions include blood and feather processing operations, dryers, centrifuges, tallow processing tanks, and percolator pans that are not enclosed. Raw material may also be a source of VOC emissions, but if the material is processed in a timely manner, these emissions are minimal.

In addition to VOC emissions, particulate matter (PM) is emitted from grinding and screening of the solids (cracklings) from the screw press and other rendering operations such as dryers processing blood and feathers. No emission data quantifying VOC, HAP, or PM emissions from the

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rendering process are available for use in developing emission factors. Only test data for a blood dryer operation were identified.

Controls -

Emissions control at rendering plants is based primarily on the elimination of odor. These controls are divided into two categories: (1) those controlling high intensity odor emissions from the rendering process, and (2) those controlling plant ventilating air emissions. The control technologies that are typically used for high intensity odors from rendering plant process emissions are waste heat boilers (incinerators) and multistage wet scrubbers.

Boiler incinerators are a common control technology because boilers can be used not only as control devices but also to generate steam for cooking and drying operations. In waste heat boilers, the waste stream can be introduced into the boiler as primary or secondary combustion air. Primary combustion air is mixed with fuel before ignition to allow for complete combustion, and secondary combustion air is mixed with the burner flame to complete combustion. Gaseous waste streams that contain noncondensibles are typically "cleaned" in a combination scrubber and entrainment separator before use as combustion air.

Multistage wet scrubbers are equally as effective as incineration for high intensity odor control and are used to about the same extent as incinerators. Sodium hypochlorite is considered to be the most effective scrubbing agent for odor removal, although other oxidants can be used. Recently, chlorine dioxide has been used as an effective scrubbing agent. Venturi scrubbers are often used to remove PM from waste streams before treatment by the multistage wet scrubbers. Plants that are located near residential or commercial areas may treat process and fugitive emissions by ducting the plant ventilation air through a single-stage wet scrubbing system to minimize odorous emissions.

In addition to the conventional scrubber control technology, activated carbon adsorption and catalytic oxidation potentially could be used to control odor; however, no rendering plants currently use these technologies. Recently, some plants have installed biofilters to control emissions.

No data are currently available for VOC or particulate emissions from rendering plants. The only available data are for emissions from blood dryers, which is an auxiliary process in meat rendering operations. Less than 10 percent of the independent rendering plants in the U. S. process whole blood. Table 9.5.3-2 provides controlled emission factors in English units for particulate matter (filterable and condensible), hydrogen sulfide, and ammonia from natural gas, direct-fired blood dryers. The filterable PM was found to be 100 percent PM-10. Emission factors are calculated on the basis of the weight of dried blood meal product. In addition to natural gas, direct-fired dryers, steam-coil, indirect blood dryers (SCC 3-02-038-12) are also used in meat rendering plants. No emission data were found for this type of dryer. The emission control system in Reference 4 consisted of a cyclone separator for collection of the blood meal product followed by a venturi wet scrubber and three packed bed scrubbers in series. The scrubbing medium for the three packed bed scrubbers was a sodium hypochlorite solution. The emission control system in Reference 5 was a mechanical centrifugal separator.

Table 9.5.3-2. EMISSION FACTORS FOR CONTROLLED BLOOD DRYERS

EMISSION FACTOR RATING: E

Pollutant	Emissions, lb/ton ^a		
Filterable PM-10 ^b (SCC 3-02-038-11)	0.76		
Condensible PM ^b (SCC 3-02-038-11)	0.46		
Hydrogen sulfide [°] (SCC 3-02-038-11)	0.08		
Ammonia [°] (SCC 3-02-038-11)	0.60		

^a Emission factors based on weight of dried blood meal product. Emissions are for natural gas, direct-fired dryers.

^b References 4-5.

° Reference 4.

References For Section 9.5.3

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9.5.4 Manure Processing

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9.5.5 Poultry Slaughtering

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9.6.1 Natural And Processed Cheese

9.6.1.1 General¹⁻³

The United States is one of the largest producers of cheese in the world. The total number of industry establishments in the United States in 1995 was 432. In 1995, total natural cheese production in the U. S., excluding cottage cheeses, was 6.9 billion pounds, and total processed cheese production was 2.3 billion pounds. Wisconsin is the leading producer of cheese in the United States, accounting for over 30 percent of all cheese production in the country.

Popular types of natural cheeses include unripened (e. g., cottage cheese, cream cheese), soft (e. g., Brie, Camembert), semi-hard (e. g., Brick, Muenster, Roquefort, Stilton), hard (e. g., Colby, Cheddar), blue veined (e. g., Blue, Gorgonzola), cooked hard cheeses (e. g., Swiss, Parmesan), and pasta filata (stretched curd, e. g., Mozzarella, Provolone). Examples of processed cheeses include American cheese and various cheese spreads, which are made by blending two or more varieties of cheese or blending portions of the same type of cheese that are in different stages of ripeness.

9.6.1.2 Process Description⁴⁻⁹

The modern manufacture of natural cheese consists of four basic steps: coagulating, draining, salting, and ripening. Processed cheese manufacture incorporates extra steps, including cleaning, blending, and melting. No two cheese varieties are produced by the same method. However, manufacturing different cheeses does not require widely different procedures but rather the same steps with variations during each step, the same steps with a variation in their order, special applications, or different ripening practices. Table 9.6.1-1 presents variations in the cheesemaking process characteristic of particular cheese varieties. This section includes a generic process description; steps specific to a single cheese variety are mentioned but are not discussed in detail.

9.6.1.2.1 Natural Cheese Manufacture -

The following sections describe the steps in the manufacture of natural cheese. Figure 9.6.1-1 presents a general process diagram.

Milk Preparation -

Cow's milk is the most widely used milk in cheese processing. First, the milk is homogenized to ensure a constant fat level. A standardizing centrifuge, which skims off the surplus fat as cream, is often used to obtain the fat levels appropriate for different varieties of cheese. Following homogenization, the milk is ready for pasteurization, which is necessary to destroy harmful micro-organisms and bacteria.

Coagulation -

Coagulation, or clotting of the milk, is the basis of cheese production. Coagulation is brought about by physical and chemical modifications to the constituents of milk and leads to the separation of the solid part of milk (the curd) from the liquid part (the whey). To initiate coagulation, milk is mixed with a starter, which is a culture of harmless, active bacteria. The enzyme rennin is also used in coagulation. Most of the fat and protein from the milk are retained in the curd, but nearly all of the lactose and some of the minerals, protein, and vitamins escape into the whey. Table 9.6.1-1 provides the primary coagulating agents and the coagulating times necessary for different varieties of cheese.

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Table 9.6.1-1. DIFFERENCES IN SELECTED CHEESEMAKING STEPS

Type of Cheese	Primary Coagulating Agent/Time	Cooking Temp. °C (°F)	Primary Draining Method	pН	Salting, %	Pressing	Ripening Period
Blue	Rennin (30 min)	33.3 (92)	Vat drain	5.4	Dry (5.0)	In molds, no surface weights	60 days minimum; 3-4 mos usually; 9 mos for more flavor
Brick	Rennin (25 min)	35.6 (96)	Vat drain	5.4	Brine (1.5)	In molds, surface weights	4-8 weeks
Camembert	Rennin (45 min)	32.2 (90)	Dip	5.1	Dry (1.5)	In molds, no surface weights	4-5 weeks
Cheddar	Rennin (25 min)	37.8 (100)	Vat drain	5.2	Dry (1.5)	Horizontal hydraulic press	60 days minimum; 3-6 mos usually; 12 or longer for sharp flavor
Cottage	Acid (5 hr)	48.9 (120)	Vat drain	4.6	Dry (1.0)	Vat packing	Unripened
Cream	Acid (5 hr)	57.2 (135)	Ноор	4.6	Dry (1.0)	Bag packing	Unripened
Mozzarella	Rennin (30 min)	32.2 (90)	Vat drain	5.3	Brine (0.7)	Bag packing	Unripened to 2 months
Provolone	Rennin (20 min)	47.8 (118)	Vat drain	5.3	Brine (1.5)	Vat packing	6-14 months
Ricotta	Acid (30 min)	80.0 (176)	Ноор	5.9	Dry (0.5)	Can packing	Unripened
Romano	Rennin (20 min)	46.7 (116)	Dip	5.3	Dry (5.0)	In molds, surface weights	5 months min.; 12 months for grating
Swiss	Rennin (30 min)	53.3 (128)	Dip	6.2	Brine (1.6)	Vertical hydraulic press	2 months min.; 2-9 months usually

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Source: Reference 8

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Figure 9.6.1-1. Natural cheese manufacture. (Source Classification Code in parentheses.)

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Curd Treatment -

After the curd is formed, it is cut into small pieces to speed whey expulsion and increase the surface area. The curd particles are cut into various sizes, depending on the variety of cheese being made. Cutting the curd into small cubes reduces the moisture content of the curd, whereas creating larger cubes increases the moisture content.

Following the cutting step, the curd is cooked, which contracts the curd particles and acts to remove whey, develop texture, and establish moisture control. The cut curds and whey are heated and agitated. Table 9.6.1-1 provides the cooking temperatures required to produce typical varieties of cheeses.

Curd Drainage -

The next step in cheese manufacture, drainage, involves separating the whey from the curd. Drainage can be accelerated by either heat treatment or mechanical treatment, such as cutting, stirring, oscillating, or pressing. After the curd is dry, it is cut into blocks which can then be filled into cheese hoops for further draining and pressing. Table 9.6.1-1 gives the primary draining methods for a variety of cheeses.

For some cheeses, special applications and procedures occur immediately before, during, or after the draining stage. For example, internally ripened, or blue veined, cheeses (e. g., Blue, Roquefort) are usually seeded with penicillium powder prior to drainage. Cooked hard cheeses (e. g., Parmesan) are stirred and warmed to accelerate and complete the separation of the whey. The separated whey may be treated and disposed of; shipped offsite in liquid or concentrated form for use as animal feed; used to make whey cheese; dried for lactose, mineral, or protein recovery; or dried for use as a food additive or use in the manufacture of processed cheese.

Curd Knitting -

Knitting, or transforming, the curd allows the accumulating lactic acid to chemically change the curd; knitting also includes salting and pressing. This step leads to the characteristic texture of different cheeses. During the curd knitting stage, Provolone and Mozzarella cheeses are pulled and processed (these cheeses are then kneaded, drawn, shaped, and smoothed); a bean gum or some other type of gum is added to cream cheese to stabilize and stiffen it; and a creaming agent (cream and/or milk) is added to cottage cheese. During this period, specific pH levels are controlled to produce different varieties of cheese (see Table 9.6.1-1).

To salt the cheese, coarse salt is spread over the surface of the cheese or the pressed cheese is immersed in a salt solution. Salting further completes the drainage of the cheese and also affects rind formation, growth of microorganisms, and enzyme activity. Table 9.6.1-1 provides the salting method and salt percentage necessary to produce a particular variety of cheese.

Pressing determines the characteristic shape of the cheese by compacting the texture, extruding free whey from the curds, and completing the curd knitting. Pressing involves confining the wet, warm curds in a form or cloth bag. With some cheeses, vertical pressing is used; others require vacuum pressing to remove occluded air and give a close-knit body. See Table 9.6.1-1 for the different pressing practices for various cheeses.

Ripening -

During the ripening or curing stage, varieties of cheeses acquire their own unique textures, aromas, appearances, and tastes through complex physical and chemical changes that are controlled as much as possible by adjusting temperature, humidity, and duration of ripening. For all cheeses, the purpose of ripening is to allow beneficial bacteria and enzymes to transform the fresh curd into a cheese of a specific flavor, texture, and appearance. Cottage and cream cheeses are not ripened, and usually have a bland flavor and soft body.

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Some cheeses require the application of a special ripening agent to create a particular taste or texture. For example, some cheeses rely wholly on surface bacteria and yeast applied to their exteriors for curing and ripening (e. g., Brick, Brie, Camembert); others require injection of particular bacteria and molds (e. g., Blue) or gas-forming microorganisms (e. g., Swiss). It is during the ripening stage that the rind or crust forms on the cheese's surface. The rind controls the loss of moisture from the internal part of the cheese and regulates the escape of gases released during ripening.

Preserving And Packaging -

Modern cheese packaging protects the food from microorganisms and prevents moisture loss. Ripened cheeses must undergo special procedures during packaging for preservative reasons. Unripened cheeses are packaged immediately after the curd is collected and must be immediately refrigerated.

Many ripened cheeses are coated in wax to protect them from mold contamination and to reduce the rate of moisture loss. Cheeses that naturally develop a thick, tightly woven rind, such as Swiss, do not require waxing. A second method of ripened cheese packaging involves applying laminated cellophane films to unwaxed cheese surfaces. The most common packaging film consists of two laminated cellophane sheets and a brown paper overlay necessary for shipping. A variation includes a metal foil wrap.

9.6.1.2.2 Processed Cheese Manufacture -

Nearly one-third of all cheese produced in the United States consists of processed cheese and processed cheese products. There are many different types of final products in processed cheese manufacture. These cheeses are distinguished from one another not only by their composition but by their presentation as individual portions, individual slices, rectangular blocks, or special presentation as cylinders or tubes.

Processed cheese is made by pasteurizing, emulsifying, and blending natural cheese. Processed cheese foods, spreads, and cold pack cheeses contain additional ingredients, such as nonfat milk solids and condiments. Several varieties of natural cheeses may be mixed, and powdered milk, whey, cream or butter, and water may be added. The following section describes the basic steps necessary for producing pasteurized process cheese, the most common processed cheese.

Pasteurized Process Cheese -

Cheeses are selected to be processed from both mild and sharp cheeses. For example, American cheese is made from Cheddar and Colby cheeses. Once selected, the cheeses must be analyzed for their fat and moisture contents to determine the proper amount of emulsifiers and salts to be added. Cheese surfaces are cleaned by scraping and trimming, and the rinds are removed. After cleaning, the cheese blocks are ground in massive grinders, combined, and the cheese mixture is heated. At this point, the melted cheese separates into a fat and serum. Emulsifiers are added to disperse the fat, and create a uniform, homogenous mass.

The molten cheese is removed quickly from the cookers and is pumped or dropped into packaging hoppers. The cheese is packaged in the absence of oxygen to inhibit the growth of mold. The cheese is usually wrapped in lacquered aluminum foil or in aluminum foil-lined cardboard or plastic boxes. For sliced processed cheese, the molten cheese is spread uniformly by chilled steel rollers and cut by rotary knives to consumer size.

Processed Cheese Foods -

Other processed cheeses that are similar to the above in manufacturing are also commonly produced. For example, to produce pasteurized process cheese food, one or more of the following optional dairy ingredients are added: cream, milk, skim milk, buttermilk, and/or cheese whey. The result is a processed cheese food that is higher in moisture and lower in fat than pasteurized process cheese. After heating, processed cheese intended for spreading undergoes a creaming step, which includes mechanical kneading of the hot cheese and addition of various dairy products and other additives. Other processed cheese products include cold-packed cheese, cold-packed cheese food, and reduced fat cheeses. All processed cheeses may be enhanced with salt, artificial colorings, spices or flavorings, fruits, vegetables, and meats.

Grated and powdered cheeses are produced by removing the moisture from one or more varieties of cheeses and grinding, grating, or shredding the cheese(s). Mold-inhibiting ingredients and anti-caking agents may be added as well. Dehydration takes such forms as tray drying, spray or atomized drying, and freeze drying. Popular types of grated cheese include Parmesan, Romano, Mozzarella, and Cheddar. Cheese powders, such as those made from Cheddar cheese, may be used to flavor pasta, or added to bread dough, potato chips, or dips.

9.6.1.3 Emissions And Controls

Particulate emissions from cheese manufacture occur during cheese or whey drying, and may occur when the cheese is grated or ground before drying. CO_2 emissions from direct-fired dryers are primarily from the combustion of fuel, natural gas. Cheese dryers are used in the manufacture of grated or powdered cheeses. Whey dryers are used in some facilities to dry the whey after it has been separated from the curd following coagulation. VOC emissions may occur in the coagulation and/or ripening stages. Particulate emissions from cheese and whey dryers are controlled by wet scrubbers, cyclones, or fabric filters. Cyclones are also used for product recovery. Emission factors for cheese drying and whey drying in natural and processed cheese manufacture are shown in Table 9.6.1-2.

	Average emission factor ^b			actor ^b
Source	Pollutant	lb/ton	Rating	Ref.
Cheese dryer (SCC 3-02-030-20)	Filterable PM Condensible inorganic PM Condensible organic PM	2.5 0.29 0.44	D D D	1,2,3 2,3 1,2,3
Whey dryer (SCC 3-02-030-10)	Filterable PM Condensible PM	1.24 0.31	D D	4,6,7 4,6,7

Table 9.6.1-2.	PARTICULATE EMISSION FACTORS FOR NATURAL AND
	PROCESSED CHEESE MANUFACTURE ^a

^a Emission factor units are lb/ton of dry product. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code.

^b Emission factors for cheese dryers represent average values for controlled emissions based on wet scrubbers or venturi scrubbers. Factors for whey dryers are average values for controlled emissions based on cyclones, wet scrubbers, or fabric filters.

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9.7 Cotton Ginning

9.7.1 General¹⁻⁸

Cotton ginning takes place throughout the area of the United States known as the Sunbelt. Four main production regions can be designated:

- Southeast-Virginia, North Carolina, South Carolina, Georgia, Alabama, and Florida
- Mid-South-Missouri, Tennessee, Mississippi, Arkansas, and Louisiana
- Southwest—Texas and Oklahoma
- West-New Mexico, Arizona, and California

The majority of the ginning facilities are located in Texas, Mississippi, Arkansas, California, and Louisiana.

The industry trend is toward fewer gins with higher processing capacity. In 1979, 2,332 active gins in the United States produced 14,161,000 bales of cotton. By the 1994/1995 season, the number of cotton gins in the United States dropped to 1,306, but about 19,122,000 bales were produced. The average volume processed per gin in 1994/1995 was 14,642 bales.

Cotton ginning is seasonal. It begins with the maturing of the cotton crop, which varies by region, and ends when the crop is finished. Each year the cotton ginning season starts in the lower Southwest region in midsummer, continues through the south central and other geographical regions in late summer and early autumn, and ends in the upper Southwest region in late autumn and early winter. Overall, U. S. cotton is ginned between October 1 and December 31, with the bulk of the crop from each geographical region being ginned in 6 to 8 weeks. During the remainder of the year, the gin is idle.

All U. S. cotton in commercial production is now harvested by machines of two types, picking and stripping. Machine-picked cotton accounts normally for 70 to 80 percent of the total cotton harvested, while the rest is machine stripped. Machine picking differs from machine stripping mainly in the method by which the cotton lint and seed are removed from the plant. Machine picking is done by a spindle picker machine that selectively separates the exposed seed cotton from the open capsules, or bolls. In contrast, the mechanical stripper removes the entire capsule, with lint plus bract, leaf, and stem components in the harvested material.

Strippers collect up to six times more leaves, burs, sticks, and trash than the spindle picker machines. This higher ratio of trash to lint requires additional equipment for cleaning and trash extraction. Stripper-harvested cotton may produce 1,000 pounds of trash per 500-pound bale of lint, compared to 150 pounds of trash per 500-pound bale from spindle picking.

The modular system of seed cotton storage and handling has been rapidly adopted. This system stores seed cotton in the field after harvesting until the gin is ready to process it. Modules can also be transported longer distances, allowing gins to increase productivity. In 1994, 78 percent of the U.S. crop was handled in modules.

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9.7.2 Process Description^{2,5-7}

Figure 9.7-1 is a flow diagram of a typical cotton-ginning process. Each of the five ginning steps and associated equipment is described below.

9.7.2.1 Unloading System -

Module trucks and trailers transport cotton from the field to the gin. A pneumatic system removes the cotton from the trailers, and either a pneumatic system or a module feeder removes the cotton from modules. A combination conveyer and pneumatic system conveys the cotton to a separator and feed control unit. Prior to this first separator point, some gins use a stone and green boll trap for preliminary trash removal. The screen assembly in the separator allows air to escape but collects the cotton and allows it to fall into the feed control unit. The conveying air flows from the separator to a cyclone system, where it is cleaned and discharged to the atmosphere.

9.7.2.2 Seed Cotton Cleaning System -

Cotton is subjected to three basic conditioning processes--drying, cleaning, and extracting--before it is processed for separation of lint and seed. To ensure adequate conditioning, cotton gins typically use two conditioning systems (drying, cleaning, and extracting) in series.

Seed cotton dryers are designed to reduce lint cotton moisture content to 5 to 8 percent to facilitate cleaning and fiber/seed separation. A high-pressure fan conveys seed cotton through the drying system to the first seed cotton cleaner, which loosens the cotton and removes fine particles of foreign matter (e. g., leaf trash, sand, and dirt). In the second cleaner, large pieces (e. g., sticks, stems, and burs) are removed from the cotton by a different process, referred to as "extracting". Different types of extractors may be used, including bur machines, stick machines, stick and bur machines, stick and green leaf extractors, and extractor/feeders. These machines remove burs, sticks, stems, and large leaves, pneumatically conveying them to the trash storage area. The cotton is pneumatically conveying step. Typically, all conveying air is cleaned by a cyclone before being released to the atmosphere.

9.7.2.3 Overflow System -

After cleaning, the cotton enters a screw conveyor distributor, which apportions the cotton to the extractor/feeders at a controlled rate. The extractor/feeders drop the cotton into the gin stands at the recommended processing rates. If the flow of cotton exceeds the limit of the extractor/feeder systems, the excess cotton flows into the overflow hopper. A pneumatic system (overflow separator) then returns this cotton back to the screw conveyor distributor, as required. Typically, the air from this system is routed through a cyclone and cleaned before being exhausted to the atmosphere.

9.7.2.4 Ginning and Lint Handling System -

Cotton enters the gin stand through a "huller front", which performs some cleaning. Saws grasp the locks of cotton and draw them through a widely spaced set of "huller ribs" that strip off hulls and sticks. (New gin stands do not have huller ribs.) The cotton locks are then drawn into the roll box, where fibers are separated from the seeds. After all the fibers are removed, the seeds slide down the face of the ginning ribs and fall to the bottom of the gin stand for subsequent removal to storage. Cotton lint is removed from the saws by a rotating brush, or a blast of air, and is conveyed pneumatically to the lint cleaning system for final cleaning and combing. The lint cotton is removed from the first lint cleaner, where saws comb the lint cotton again and remove part of the remaining leaf particles, grass, and motes. Most condensers are covered with fine mesh wire or fine perforated metal, which acts to filter short lint fibers and some dust from the conveying air.



Figure 9.7-1. Flow diagram of cotton ginning process. (Source Classification Codes in parentheses.)

9.7.2.5 Battery Condenser And Baling System -

Lint cotton is pneumatically transported from the lint cleaning system to a battery condenser, which is a drum covered with fine mesh screen or fine perforated metal that separates the lint cotton from the conveying air. The lint cotton is formed into batts and fed into a baling press, which compresses the cotton into uniform bales.

Most gins use a double-press box for packaging the cotton into bales. The lint drops into one press box and fills it while a bale is being pressed and strapped in the other box. Approximately 480 lb (217 kilograms [kg]) of cotton is pressed into a bale before it is wrapped with a cover and strapped. Modern gins are presently equipped with higher-tonnage bale presses that produce the more compact universal density cotton bales. In 1995, 96 percent of the U.S. crop was pressed into universal density bales at the gins. The finished cotton bale is transported to the textile mill for processing into yarn. Motes are sometimes cleaned and baled also.

9.7.3 Emissions And Controls¹⁻²⁴

Particulate matter (PM) is the primary air pollutant emitted from cotton ginning. Available data indicate that about 37 percent of the total PM emitted (following control systems) from cotton ginning is PM less than or equal to 10 microns in aerodynamic diameter (PM-10). The PM is composed of fly lint, dust, fine leaves, and other trash. Figure 9.7-1 shows the typical PM emission points in the ginning process. Particulate matter emissions are typically greater at gins processing stripper-harvested cotton than at gins processing picker-harvested cotton. Also, PM emissions from the first cotton harvest at a given facility are typically lower than emissions from subsequent harvests.

Control devices used to control PM emissions from cotton ginning operations include cyclones, fine screen coverings, and perforated metal drums. Cyclones may be used to control the sources with high pressure exhaust or all of the operations at a gin. Two types of cyclones that are used are 2D-2D and 1D-3D cyclones. Both the body and the cone of a 2D-2D cyclone are twice as long as the cyclone diameter. The body of a 1D-3D cyclone is the same length as the diameter, and the cone length is three times the diameter. In many cases, 1D-3D cyclones display slightly higher PM control efficiencies than 2D-2D cyclones.

Screen coverings and perforated drums may be used to control PM emissions from sources with low-pressure exhaust, including the battery condenser and lint cleaners.

Table 9.7-1 presents PM and PM-10 emission factors for cotton gins controlled primarily by 1D-3D or 2D-2D cyclones. Emission factors for lint cleaners and battery condensers with screened drums or cages are also presented. Emission factors for total gin emissions are shown for two different gin configurations. The emission factors for "Total No.1" represent total PM and PM-10 emissions from gins with all exhaust streams controlled by high-efficiency cyclones. The emission factors for "Total No. 2" represent total PM and PM-10 emissions from gins with screened drums or cages controlling the lint cleaner and battery condenser exhausts and high-efficiency cyclones controlling all other exhaust streams. The emission factors for the No. 3 dryer and cleaner, cyclone robber system, and mote trash fan are not included in either total because these processes are not used at most cotton gins. However, these factors should be added into the total for a particular gin if these processes are used at that gin.

Source	Total PM, lb/bale	EMISSION FACTOR RATING	PM-10, lb/bale	EMISSION FACTOR RATING
Unloading fan (SCC 3-02-004-01)	0.29 ^b	D	0.12°	D
No. 1 dryer and cleaner (SCC 3-02-004-20)	0.36 ^d	D	0.12°	D
No. 2 dryer and cleaner (SCC 3-02-004-21)	0.24 ^f	D	0.093 ^g	D
No. 3 dryer and cleaner ^h (SCC 3-02-004-22)	0.095	D	0.033	D
Overflow fan' (SCC 3-02-004-25)	0.071	D	0.026	D
Lint cleaners (SCC 3-02-004-07) with high-efficiency cyclones ^k with screened drums or cages ^m	0.58 1.1	D E	0.24 ND	D NA
Cyclone robber system ^a (SCC 3-02-004-30)	0.18	D	0.052	D
Mote fan (SCC 3-02-004-35)	0.28 ^p	D	0.13ª	D
Mote trash fan' (SCC 3-02-004-36)	0.077	D	0.021	D
Battery condenser (SCC 3-02-004-08) with high-efficiency cyclones ⁶ with screened drums or cages ^m	0.039 0.17	D E	0.014 ND	D NA
Master trash fan (SCC 3-02-004-03)	0.54 ^t	D	0.074 ^u	D
Cotton gin total No. 1 ^v (SCC 3-02-004-10)	2.4	D	0.82	D
Cotton gin total No. 2 ^w (SCC 3-02-004-10)	3.1	Е	1.2	E

Table 9.7-1. EMISSION FACTORS FOR COTTON GINS CONTROLLED WITH HIGH-EFFICIENCY CYCLONES^a

- Emission factor units are lb of pollutant per bale of cotton processed. Emissions are controlled by 1D-3D or 2D-2D high-efficiency cyclones unless noted. SCC = source classification code. ND = no data available. To convert from lb/bale to kg/bale, multiply by 0.45.
- ^b References 13-15,17,19-20,22,24.
- [°] References 13-14,17,22,24.
- ^d References 12-14,17,19,21.
- ^e References 12-14,17,21.
- ^f References 9,12,14,17,19,24.
- ^g References 9,12,14,17,24.
- ^h References 10,16. Most gins do not include this source, and these emission factors are not included in the total gin emission factors shown. However, these factors should be added into the total for a particular gin if this source is part of that gin.
- ¹ References 10,14,17,24.
- ^k References 13-14,17,21-23. Emission factors are included in Total No. 1, but are not included in Total No. 2.
- References 18-20. Emission factors are not included in Total No. 1, but are included in Total No. 2.
- ⁿ Reference 22. Most gins do not include this source, and these emission factors are not included in the total gin emission factors shown. However, these factors should be added into the total for a particular gin if this source is part of that gin.
- ^p References 11-14,17,19-20,23-24.
- ^q References 11-14,17,24.
- ^r References 10-11,22. Many gins do not include this source, and these emission factors are not included in the total gin emission factors shown. However, these factors should be added into the total for a particular gin if these sources are part of that gin.
- ^{*} References 14,16-17,23-24. Emission factors are included in Total No. 1, but are not included in Total No. 2.
- ^t References 15,19,22.

- ^v Total for gins with high-efficiency cyclones on all exhaust streams. Does not include emission factors for the No. 3 dryer and cleaner, cyclone robber system, mote trash fan, lint cleaners with screened drums or cages, and battery condenser with screened drums or cages.
- Total for gins with screened drums or cages on the lint cleaners and battery condenser and highefficiency cyclones on all other exhaust streams. Does not include emission factors for the No. 3 dryer and cleaner, cyclone robber system, mote trash fan, lint cleaners with high-efficiency cyclones, and battery condenser with high-efficiency cyclones. PM-10 emissions from lint cleaners and battery condensers with screened drums or cages are estimated as 50 percent of the total PM emissions from these sources.
- 9.7.4 Summary of Terminology

<u>Bale</u> – A compressed and bound package of cotton lint, typically weighing about 480 lb.

<u>Batt</u> — Matted lint cotton.

 \underline{Boll} — The capsule or pod of the cotton plant.

<u>Bur</u> (or burr) — The rough casing of the boll. Often referred to as hulls after separation from the cotton.

<u>Condenser</u> — A perforated or screened drum device designed to collect lint cotton from the conveying airstream, at times into a batt.

<u>Cotton</u> — General term used variously to refer to the cotton plant (genus Gossypium); agricultural crop; harvest product; white fibers (lint) ginned (separated) from the seed; baled produce; and yarn or fabric products. Cotton is classified as upland or extra long staple depending on fiber length.

<u>Cottonseed</u> — The seed of the cotton plant, separated from its fibers. The seeds constitute 40 percent to 55 percent of the seed cotton (depending on the amount of trash) and are processed into oil meal, linters, and hulls, or are fed directly to cattle.

<u>Cyclone</u> — A centrifugal air pollution control device for separating solid particles from an airstream.

<u>Cyclone robber system</u> - A secondary cyclone trash handling system. These systems are not used at most cotton gins.

<u>Cylinder cleaner</u> — A machine with rotating spiked drums that open the locks and clean the cotton by removing dirt and small trash.

<u>Extractor</u> — Equipment for removing large trash pieces (sticks, stems, burs, and leaves). The equipment may include one or more devices, including a stick machine, bur machine, green-leaf machine, and a combination machine.

<u>Extractor-feeder</u> — A device that gives seed cotton a final light extraction/cleaning and then feeds it at a controlled rate to the gin stand.

<u>Fly lint</u> (or lint fly) — Short (less than 50 μ m) cotton fibers, usually emitted from condensers and mote fan.

^u References 15,22.

 $\underline{Gin \ stand}$ — The heart of the ginning plant where gin saws (usually several in parallel) separate the cotton lint from the seeds.

<u>High pressure side</u> — The portion of the process preceding the gin stand (including unloading, drying, extracting, cleaning, and overflow handling systems) in which material is conveyed by a higher pressure air, and exhausts are typically controlled by cyclones.

<u>Lint cleaner</u> — A machine for removing foreign material from lint cotton.

Lint cotton – Cotton fibers from which the trash and seeds have been removed by the gin.

<u>Low pressure side</u> — The portion of the process following the gin stand (including lint cotton cleaning and batt formation process) in which material is conveyed by low pressure air, and exhausts are typically controlled by condensers.

<u>Mote</u> — A small group of short fibers attached to a piece of the seed or to an immature seed. Motes may be cleaned and baled.

<u>Picker harvester</u> — A machine that removes cotton lint and seeds from open bolls with rotating spindles, leaving unopened bolls on the plant. "First pick" cotton is obtained from the initial harvest of the season. It usually contains less trash than "second pick" cotton, obtained later in the harvest season. "Ground cotton" is obtained by picking up between the rows at season's end and has a high trash content.

<u>Seed cotton</u> – Raw cotton, containing lint, seed, and some waste material, as it comes from the field.

<u>Separator</u> — A mechanical device (e.g., wire screen with rotary rake) that separates seed cotton from conveying air.

<u>Stripper harvester</u> — A machine that strips all bolls — opened (mature) and unopened (immature or green) — from the plant; strippers are used on short cotton plants, grown in arid areas of Texas, Oklahoma, and New Mexico. They collect larger amounts of trash (leaves, stems, and sticks) than picker harvesters.

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9.8.1 Canned Fruits And Vegetables

9.8.1.1 General¹⁻²

The canning of fruits and vegetables is a growing, competitive industry, especially the international export portion. The industry is made up of establishments primarily engaged in canning fruits, vegetables, fruit and vegetable juices; processing ketchup and other tomato sauces; and producing natural and imitation preserves, jams, and jellies.

9.8.1.2 Process Description³⁻⁶

The primary objective of food processing is the preservation of perishable foods in a stable form that can be stored and shipped to distant markets during all months of the year. Processing also can change foods into new or more usable forms and make foods more convenient to prepare.

The goal of the canning process is to destroy any microorganisms in the food and prevent recontamination by microorganisms. Heat is the most common agent used to destroy microorganisms. Removal of oxygen can be used in conjunction with other methods to prevent the growth of oxygen-requiring microorganisms.

In the conventional canning of fruits and vegetables, there are basic process steps that are similar for both types of products. However, there is a great diversity among all plants and even those plants processing the same commodity. The differences include the inclusion of certain operations for some fruits or vegetables, the sequence of the process steps used in the operations, and the cooking or blanching steps. Production of fruit or vegetable juices occurs by a different sequence of operations and there is a wide diversity among these plants. Typical canned products include beans (cut and whole), beets, carrots, corn, peas, spinach, tomatoes, apples, peaches, pineapple, pears, apricots, and cranberries. Typical juices are orange, pineapple, grapefruit, tomato, and cranberry. Generic process flow diagrams for the canning of fruits, vegetables, and fruit juices are shown in Figures 9.8.1-1, 9.8.1-2, and 9.8.1-3. The steps outlined in these figures are intended to the basic processes in production. A typical commercial canning operation may employ the following general processes: washing, sorting/grading, preparation, container filling, exhausting, container sealing, heat sterilization, cooling, labeling/casing, and storage for shipment. In these diagrams, no attempt has been made to be product specific and include all process steps that would be used for all products. Figures 9.8.1-1 and 9.8.1-2 show optional operations, as dotted line steps, that are often used but are not used for all products. One of the major differences in the sequence of operations between fruit and vegetable canning is the blanching operation. Most of the fruits are not blanched prior to can filling whereas many of the vegetables undergo this step. Canned vegetables generally require more severe processing than do fruits because the vegetables have much lower acidity and contain more heat-resistant soil organisms. Many vegetables also require more cooking than fruits to develop their most desirable flavor and texture. The methods used in the cooking step vary widely among facilities. With many fruits, preliminary treatment steps (e. g., peeling, coring, halving, pitting) occur prior to any heating or cooking step but with vegetables, these treatment steps often occur after the vegetable has been blanched. For both fruits and vegetables, peeling is done either by a mechanical peeler, steam peeling, or lye peeling. The choice depends upon the type of fruit or vegetable or the choice of the company.



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FRUIT CANNING



VOC AND PM EMISSIONS

Figure 9.8.1-2. Generic process diagram for vegetable canning.





Figure 9.8.1-3. Generic process diagram for juice canning.

Some citrus fruit processors produce dry citrus peel, citrus molasses and D-limonene from the peels and pulp residue collected from the canning and juice operations. Other juice processing facilities use concentrates and raw commodity processing does not occur at the facility. The peels and residue are collected and ground in a hammermill, lime is added to neutralize the acids, and the product pressed to remove excess moisture. The liquid from the press is screened to remove large particles, which are recycled back to the press, and the liquid is concentrated to molasses in an evaporator. The pressed peel is sent to a direct-fired hot-air drier. After passing through a condenser to remove the D-limonene, the exhaust gases from the drier are used as the heat source for the molasses evaporator.

Equipment for conventional canning has been converting from batch to continuous units. In continuous retorts, the cans are fed through an air lock, then rotated through the pressurized heating chamber, and subsequently cooled through a second section of the retort in a separate cold-water cooler. Commercial methods for sterilization of canned foods with a pH of 4.5 or lower include use of static retorts, which are similar to large pressure cookers. A newer unit is the agitating retort, which mechanically moves the can and the food, providing quicker heat penetration. In the aseptic packaging process, the problem with slow heat penetration in the in-container process are avoided by sterilizing and cooling the food separate from the container. Presterilized containers are then filled with the sterilized and cooled product and are sealed in a sterile atmosphere.

To provide a closer insight into the actual processes that occur during a canning operation, a description of the canning of whole tomatoes is presented in the following paragraphs. This description provides more detail for each of the operations than is presented in the generic process flow diagrams in Figures 9.8.1-1, 9.8.1-2, and 9.8.1-3.

Preparation -

The principal preparation steps are washing and sorting. Mechanically harvested tomatoes are usually thoroughly washed by high-pressure sprays or by strong-flowing streams of water while being passed along a moving belt or on agitating or revolving screens. The raw produce may need to be sorted for size and maturity. Sorting for size is accomplished by passing the raw tomatoes through a series of moving screens with different mesh sizes or over differently spaced rollers. Separation into groups according to degree of ripeness or perfection of shape is done by hand; trimming is also done by hand.

Peeling And Coring -

Formerly, tomatoes were initially scalded followed by hand peeling, but steam peeling and lye peeling have also become widely used. With steam peeling, the tomatoes are treated with steam to loosen the skin, which is then removed by mechanical means. In lye peeling, the fruit is immersed in a hot lye bath or sprayed with a boiling solution of 10 to 20 percent lye. The excess lye is then drained and any lye that adheres to the tomatoes is removed with the peel by thorough washing.

Coring is done by a water-powered device with a small turbine wheel. A special blade mounted on the turbine wheel spins and removes the tomato cores.

Filling -

After peeling and coring, the tomatoes are conveyed by automatic runways, through washers, to the point of filling. Before being filled, the can or glass containers are cleaned by hot water, steam, or air blast. Most filling is done by machine. The containers are filled with the solid product and then usually topped with a light puree of tomato juice. Acidification of canned whole tomatoes with 0.1 to 0.2 percent citric acid has been suggested as a means of increasing acidity to a safer and

more desirable level. Because of the increased sourness of the acidified product, the addition of 2 to 3 percent sucrose is used to balance the taste. The addition of salt is important for palatability.

Exhausting -

The objective of exhausting containers is to remove air so that the pressure inside the container following heat treatment and cooling will be less than atmospheric. The reduced internal pressure (vacuum) helps to keep the can ends drawn in, reduces strain on the containers during processing, and minimizes the level of oxygen remaining in the headspace. It also helps to extend the shelf life of food products and prevents bulging of the container at high altitudes.

Vacuum in the can may be obtained by the use of heat or by mechanical means. The tomatoes may be preheated before filling and sealed hot. For products that cannot be preheated before filling, it may be necessary to pass the filled containers through a steam chamber or tunnel prior to the sealing machine to expel gases from the food and raise the temperature. Vacuum also may be produced mechanically by sealing containers in a chamber under a high vacuum.

Sealing -

In sealing lids on metal cans, a double seam is created by interlocking the curl of the lid and flange of the can. Many closing machines are equipped to create vacuum in the headspace either mechanically or by steam-flow before lids are sealed.

Heat Sterilization -

During processing, microorganisms that can cause spoilage are destroyed by heat. The temperature and processing time vary with the nature of the product and the size of the container.

Acidic products, such as tomatoes, are readily preserved at $100^{\circ}C$ (212°F). The containers holding these products are processed in atmospheric steam or hot-water cookers. The rotary continuous cookers, which operate at 100°C (212°F), have largely replaced retorts and open-still cookers for processing canned tomatoes. Some plants use hydrostatic cookers and others use continuous-pressure cookers.

Cooling -

After heat sterilization, containers are quickly cooled to prevent overcooking. Containers may be quick cooled by adding water to the cooker under air pressure or by conveying the containers from the cooker to a rotary cooler equipped with a cold-water spray.

Labeling And Casing –

After the heat sterilization, cooling, and drying operations, the containers are ready for labeling. Labeling machines apply glue and labels in one high-speed operation. The labeled cans or jars are the packed into shipping cartons.

9.8.1.3 Emissions And Controls^{4,6-9}

Air emissions may arise from a variety of sources in the canning of fruits and vegetables. Particulate matter (PM) emissions result mainly from solids handling, solids size reduction, drying (e. g., citrus peel driers). Some of the particles are dusts, but others (particularly those from thermal processing operations) are produced by condensation of vapors and may be in the low-micrometer or submicrometer particle-size range.

The VOC emissions may potentially occur at almost any stage of processing, but most usually are associated with thermal processing steps, such as cooking, and evaporative concentration. The cooking technologies in canning processes are very high moisture processes so the predominant emissions will be steam or water vapor. The waste gases from these operations may contain PM or, perhaps, condensable vapors, as well as malodorous VOC. Particulate matter, condensable materials, and the high moisture content of the emissions may interfere with the collection or destruction of these VOC. The condensable materials also may be malodorous.

Wastewater treatment ponds may be another source of odors, even from processing of materials that are not otherwise particularly objectionable. Details on the processes and technologies used in waste water collection, treatment, and storage are presented in AP-42 Section 4.3; that section should be consulted for detailed information on the subject.

No emission data quantifying VOC, HAP, or PM emissions from the canned fruits and vegetable industry are available for use in the development of emission factors. Data on emissions from fruit and vegetable canning are extremely limited. Woodroof and Luh discussed the presence of VOC in apricots, cranberry juice, and cherry juice. Van Langenhove, et al., identified volatile compounds emitted during the blanching process of Brussels sprouts and cauliflower under laboratory and industrial conditions. Buttery, et al., studied emissions of volatile aroma compounds from tomato paste.

A number of emission control approaches are potentially available to the canning industry. These include wet scrubbers, dry sorbants, and cyclones. No information is available on controls actually used at canning facilities.

Control of VOC from a gas stream can be accomplished using one of several techniques but the most common methods are absorption, adsorption, and afterburners. Absorptive methods encompass all types of wet scrubbers using aqueous solutions to absorb the VOC. Most scrubber systems require a mist eliminator downstream of the scrubber.

Adsorptive methods could include one of four main adsorbents: activated carbon, activated alumina, silica gel, or molecular sieves. Of these four, activated carbon is the most widely used for VOC control while the remaining three are used for applications other than pollution control. Gas adsorption is a relatively expensive technique and may not be applicable to a wide variety of pollutants.

Particulate control commonly employs methods such as venturi scrubbers, dry cyclones, wet or dry electrostatic precipitators (ESPs), or dry filter systems. The most common controls are likely to be the venturi scrubbers or dry cyclones. Wet or dry ESPs could be used depending upon the particulate loading of the gas stream.

Condensation methods and scrubbing by chemical reaction may be applicable techniques depending upon the type of emissions. Condensation methods may be either direct contact or indirect contact with the shell and tube indirect method being the most common technique. Chemical reactive scrubbing may be used for odor control in selective applications.

References for Section 9.8.1

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- 5. N. W. Deroiser, *The Technology Of Food Preservation, 3rd edition*, The Avi Publishing Company, Inc., Westport, CT, 1970.
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- 7. H. J. Van Langenhove, et al., Identification Of Volatiles Emitted During The Blanching Process Of Brussels Sprouts And Cauliflower, Journal of the Science of Food and Agriculture, 55:483-487, 1991.
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9.8.2 Dehydrated Fruits And Vegetables

9.8.2.1 General¹⁻²

Dehydration of fruit and vegetables is one of the oldest forms of food preservation techniques known to man and consists primarily of establishments engaged in sun drying or artificially dehydrating fruits and vegetables. Although food preservation is the primary reason for dehydration, dehydration of fruits and vegetables also lowers the cost of packaging, storing, and transportation by reducing both the weight and volume of the final product. Given the improvement in the quality of dehydrated foods, along with the increased focus on instant and convenience foods, the potential of dehydrated fruits and vegetables is greater than ever.

9.8.2.2 Process Description¹⁻²

Dried or dehydrated fruits and vegetables can be produced by a variety of processes. These processes differ primarily by the type of drying method used, which depends on the type of food and the type of characteristics of the final product. In general, dried or dehydrated fruits and vegetables undergo the following process steps: predrying treatments, such as size selection, peeling, and color preservation; drying or dehydration, using natural or artificial methods; and postdehydration treatments, such as sweating, inspection, and packaging.

Predrying Treatments -

Predrying treatments prepare the raw product for drying or dehydration and include raw product preparation and color preservation. Raw product preparation includes selection and sorting, washing, peeling (some fruits and vegetables), cutting into the appropriate form, and blanching (for some fruits and most vegetables). Fruits and vegetables are selected; sorted according to size, maturity, and soundness; and then washed to remove dust, dirt, insect matter, mold spores, plant parts, and other material that might contaminate or affect the color, aroma, or flavor of the fruit or vegetable. Peeling or removal of any undesirable parts follows washing. The raw product can be peeled by hand (generally not used in the United States due to high labor costs), with lye or alkali solution, with dry caustic and mild abrasion, with steam pressure, with high-pressure washers, or with flame peelers. For fruits, only apples, pears, bananas, and pineapples are usually peeled before dehydration. Vegetables normally peeled include beets, carrots, parsnips, potatoes, onions, and garlic. Prunes and grapes are dipped in an alkali solution to remove the natural waxy surface coating which enhances the drying process. Next, the product is cut into the appropriate shape or form (i. e., halves, wedges, slices, cubes, nuggets, etc.), although some items, such as cherries and corn, may by-pass this operation. Some fruits and vegetables are blanched by immersion in hot water (95° to 100°C [203° to 212°F]) or exposure to steam.

The final step in the predehydration treatment is color preservation, also known as sulfuring. The majority of fruits are treated with sulfur dioxide (SO_2) for its antioxidant and preservative effects. The presence of SO_2 is very effective in retarding the browning of fruits, which occurs when the enzymes are not inactivated by the sufficiently high heat normally used in drying. In addition to preventing browning, SO_2 treatment reduces the destruction of carotene and ascorbic acid, which are the important nutrients for fruits. Sulfuring dried fruits must be closely controlled so that enough sulfur is present to maintain the physical and nutritional properties of the product throughout its expected shelf life, but not so large that it adversely affects flavor. Some fruits, such as apples, are treated with solutions of sulfite (sodium sulfite and sodium bisulfite in approximately equal

proportions) before dehydration. Sulfite solutions are less suitable for fruits than burning sulfur (SO₂ gas), however, because the solution penetrates the fruit poorly and can leach natural sugar, flavor, and other components from the fruit.

Although dried fruits commonly use SO_2 gas to prevent browning, this treatment is not practical for vegetables. Instead, most vegetables (potatoes, cabbage, and carrots) are treated with sulfite solutions to retard enzymatic browning. In addition to color preservation, the presence of a small amount of sulfite in blanched, cut vegetables improves storage stability and makes it possible to increase the drying temperature during dehydration, thus decreasing drying time and increasing the drier capacity without exceeding the tolerance for heat damage.

Drying Or Dehydration -

Drying or dehydration is the removal of the majority of water contained in the fruit or vegetable and is the primary stage in the production of dehydrated fruits and vegetables. Several drying methods are commercially available and the selection of the optimal method is determined by quality requirements, raw material characteristics, and economic factors. There are three types of drying processes: sun and solar drying; atmospheric dehydration including stationary or batch processes (kiln, tower, and cabinet driers) and continuous processes (tunnel, continuous belt, belt-trough, fluidized-bed, explosion puffing, foam-mat, spray, drum, and microwave-heated driers); and subatmospheric dehydration (vacuum shelf, vacuum belt, vacuum drum, and freeze driers).

Sun drying (used almost exclusively for fruit) and solar drying (used for fruit and vegetables) of foods use the power of the sun to remove the moisture from the product. Sun drying of fruit crops is limited to climates with hot sun and dry atmosphere, and to certain fruits, such as prunes, grapes, dates, figs, apricots, and pears. These crops are processed in substantial quantities without much technical aid by simply spreading the fruit on the ground, racks, trays, or roofs and exposing them to the sun until dry. Advantages of this process are its simplicity and its small capital investment. Disadvantages include complete dependence on the elements and moisture levels no lower than 15 to 20 percent (corresponding to a limited shelf life). Solar drying utilizes black-painted trays, solar trays, collectors, and mirrors to increase solar energy and accelerate drying.

Atmospheric forced-air driers artificially dry fruits and vegetables by passing heated air with controlled relative humidity over the food to be dried, or by passing the food to be dried through the heated air, and is the most widely used method of fruit and vegetable dehydration. Various devices are used to control air circulation and recirculation. Stationary or batch processes include kiln, tower (or stack), and cabinet driers. Continuous processes are used mainly for vegetable dehydration and include tunnel, continuous belt, belt-trough, fluidized-bed, explosion puffing, foam-mat, spray, drum, and microwave-heated driers. Tunnel driers are the most flexible, efficient, and widely used dehydration system available commercially.

Subatmospheric (or vacuum) dehydration occurs at low air pressures and includes vacuum shelf, vacuum drum, vacuum belt, and freeze driers. The main purpose of vacuum drying is to enable the removal of moisture at less than the boiling point under ambient conditions. Because of the high installation and operating costs of vacuum driers, this process is used for drying raw material that may deteriorate as a result of oxidation or may be modified chemically as a result of exposure to air at elevated temperatures. There are two categories of vacuum driers. In the first category, moisture in the food is evaporated from the liquid to the vapor stage, and includes vacuum shelf, vacuum drum, and vacuum belt driers. In the second category of vacuum driers, the moisture of the food is removed from the product by sublimination, which is converting ice directly into water vapor. The advantages of freeze drying are high flavor retention, maximum retention of nutritional value,

minimal damage to the product texture and structure, little change in product shape and color, and a finished product with an open structure that allows fast and complete rehydration. Disadvantages include high capital investment, high processing costs, and the need for special packing to avoid oxidation and moisture gain in the finished product.

Postdehydration Treatments -

Treatments of the dehydrated product vary according to the type of fruit or vegetable and the intended use of the product. These treatments may include sweating, screening, inspection, instantization treatments, and packaging. Sweating involves holding the dehydrated product in bins or boxes to equalize the moisture content. Screening removes dehydrated pieces of unwanted size, usually called "fines". The dried product is inspected to remove foreign materials, discolored pieces, or other imperfections such as skin, carpel, or stem particles. Instantization treatments are used to improve the rehydration rate of the low-moisture product. Packaging is common to most all dehydrated products and has a great deal of influence on the shelf life of the dried product. Packaging of dehydrated fruits and vegetables must protect the product against moisture, light, air, dust, microflora, foreign odor, insects, and rodents; provide strength and stability to maintain original product size, shape, and appearance throughout storage, handling, and marketing; and consist of materials that are approved for contact with food. Cost is also an important factor in packaging. Package types include cans, plastic bags, drums, bins, and cartons, and depend on the end-use of the product.

9.8.2.3 Emissions And Controls^{1,3-6}

Air emissions may arise from a variety of sources in the dehydration of fruits and vegetables. Particulate matter (PM) emissions may result mainly from solids handling, solids size reduction, and drying. Some of the particles are dusts, but other are produced by condensation of vapors and may be in the low-micrometer or submicrometer particle-size range.

The VOC emissions may potentially occur at almost any stage of processing, but most usually are associated with thermal processing steps, such as blanching, drying or dehydration, and sweating. Particulate matter and condensable materials may interfere with the collection or destruction of these VOC. The condensable materials also may be malodorous. The color preservation (sulfuring) stage can produce SO_2 emissions as the fruits and vegetables are treated with SO_2 gas or sulfide solution to prevent discoloration or browning.

Wastewater treatment ponds may be another source of VOC, even from processing of materials that are not otherwise particularly objectionable. Details on the processes and technologies used in wastewater collection, treatment, and storage are presented in AP-42 Section 4.3. That section should be consulted for detailed information on the subject.

No emission data quantifying VOC, HAP, or PM emissions from the dehydrated fruit and vegetable industry are available for use in the development of emission factors. However, some data have been published on VOC emitted during the blanching process for two vegetables and for volatiles from fresh tomatoes. Van Langenhove, et al., identified volatiles emitted during the blanching process of Brussels sprouts and cauliflower under laboratory and industrial conditions. In addition, Buttery, et al., performed a quantitative study on aroma volatiles emitted from fresh tomatoes.

A number of VOC and particulate emission control techniques are available to the dehydrated fruit and vegetable industry. No information is available on the actual usage of emission control

devices in this industry. Potential options include the traditional approaches of wet scrubbers, dry sorbents, and cyclones.

Control of VOC from a gas stream can be accomplished using one of several techniques but the most common methods are absorption and adsorption. Absorptive methods encompass all types of wet scrubbers using aqueous solutions to absorb the VOC. Most scrubber systems require a mist eliminator downstream of the scrubber.

Adsorptive methods could include one of four main adsorbents: activated carbon, activated alumina, silica gel, or molecular sieves. Of these four, activated carbon is the most widely used for VOC control while the remaining three are used for applications other than pollution control. Gas adsorption is a relatively expensive technique and may not be applicable to a wide variety of pollutants.

Particulate control commonly employs methods such as venturi scrubbers, dry cyclones, wet or dry electrostatic precipitators (ESPs), or dry filter systems. The most common controls are likely to be the venturi scrubbers or dry cyclones. Wet or dry ESPs could be used depending upon the particulate loading of the gas stream.

Condensation methods and scrubbing by chemical reaction may be applicable techniques depending upon the type of emissions. Condensation methods may be either direct contact or indirect contact with the shell and tube indirect method being the most common technique. Chemical reactive scrubbing may be used for odor control in selective applications.

References For Section 9.8.2

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- 2. L. P. Somogyi and B. S. Luh, "Vegetable Dehydration", *Commercial Vegetable Processing*, Second Ed., B. S. Luh and J. G. Woodroof, Editors, An AVI Book Published by Van Nostrand Reinhold, 1988.
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- 5. R. G. Buttery, et al., "Fresh Tomato Aroma Volatiles: A Quantitative Study", J. Agric. Food Chem., 35:540-544, 1987.
- 6. H. J. Rafson, "Odor Emission Control For The Food Industry", *Food Technology*, June 1977.

9.8.3 Pickles, Sauces, and Salad Dressings

9.8.3.1 General¹

This industry includes facilities that produce pickled fruits and vegetables, salad dressings, relishes, various sauces, and seasonings. The two vegetables that account for the highest production volume in the U. S. are cucumbers (pickles) and cabbage (sauerkraut). Sauces entail a wide diversity of products but two of the more common types are Worcestershire sauce and hot pepper sauces. Salad dressings are generally considered to be products added to and eaten with salads. In 1987, 21,500 thousand people were employed in the industry. California, Georgia, Michigan, and Pennsylvania are the leading employment States in the industry.

9.8.3.2 Process Description²⁻³

Pickled Vegetables -

In the U. S., vegetables are pickled commercially using one of two general processes: brining or direct acidification (with or without pasteurization), or various combinations of these processes. For sodium chloride brining, fresh vegetables are placed in a salt solution or dry salt is added to cut or whole vegetables whereupon the vegetables undergo a microbial fermentation process activated by the lactic acid bacteria, yeasts, and other microorganisms. Direct acidification of fresh or brined vegetables, through the addition of vinegar, is a major component of commercial pickling. This process may be accompanied by pasteurization, addition of preservatives, refrigeration, or a combination of these treatments. While cucumbers, cabbage, and olives constitute the largest volume of vegetables brined or pickled in the U. S., other vegetables include peppers, onions, beans, cauliflower, and carrots.

In the United States, the term "pickles" generally refers to pickled cucumbers. Three methods currently are used to produce pickles from cucumbers: brine stock, fresh pack, and refrigerated. Smaller quantities are preserved by specialized brining methods to produce pickles for delicatessens and other special grades of pickles. Pickling cucumbers are harvested and transported to the processing plants. The cucumbers may be field graded and cooled, if necessitated by the temperature, prior to transport to the plants.

The brine stock process begins with brining the cucumbers through the addition of salt or a sodium chloride brining solution. The cucumbers undergo a fermentation process in which lactic acid is formed. During fermentation, the cucumbers are held in 5 to 8 percent salt; after fermentation, the salt content is increased weekly in 0.25 to 0.5 percent increments until the final holding strength is 8 to 16 percent salt. The cucumbers, called brine stock, are then graded and cut (optional), before being desalted by washing in an open tank with water at ambient temperature to obtain the desired salt level and processed into dill, sour, sweet, or other pickle products. Containers are filled with the cut or whole pickles, and sugar and vinegars are added. Preservatives are also added if the product is not pasteurized. The containers are then vacuum sealed and pasteurized (optional) until the temperature at the center of the cucumbers reaches about $74^{\circ}C$ ($165^{\circ}F$) for about 15 minutes. The product is then cooled, and the containers are labeled, packaged, and stored.

The fresh pack process begins with grading of the pickling cucumbers, followed by washing with water. The cucumbers are then either cut and inspected before packaging, or are sometimes "blanched" if they are to be packaged whole. The "blanching" consists of rinsing the cucumber with

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warm water to make it more pliable and easier to pack in the container. It is not a true blanching process. Containers are filled with the cut or whole cucumbers, and then salt, spices, and vinegars are added. The containers are then vacuum sealed and heated (pasteurized) until the temperature at the center of the cucumbers reaches about 74°C (165°F) for about 15 minutes. The product is then cooled, and the containers are labeled, packaged, and stored.

The refrigerated process begins with grading of the pickling cucumbers, followed by washing with water. The washed cucumbers are packed into containers, and then salt, spices, vinegars, and preservatives (primarily sodium benzoate) are added. The containers are then vacuum sealed, labeled, and refrigerated at 34° to 40°F. In this process, the cucumbers are not heat-processed before or after packing.

In the sauerkraut process the cabbage is harvested, transported to the processing plant, washed, and prepared for the fermentation by coring, trimming, and shredding. The shredded cabbage is conveyed to a fermentation tank where salt is added up to a final concentration of 2 to 3 percent (preferably 2.25 percent), by weight. After salt addition, the mixture is allowed to ferment at ambient temperature in a closed tank. If insufficient salt is added or air is allowed to contact the surface of the cabbage, yeast and mold will grow on the surface and result in a softening of the final sauerkraut product. When fermentation is complete, the sauerkraut contains 1.7 to 2.3 percent acid, as lactic acid. Following fermentation, the sauerkraut is packaged in cans, plastic bags, or glass containers; cans are the most prevalent method. In the canning process, the sauerkraut, containing the original or diluted fermentation liquor, is heated to 85° to 88°C (185° to 190°F) by steam injection in a thermal screw and then packed into cans. The cans are steam exhausted, sealed, and cooled. After cooling, the cans are labeled, packed, and stored for shipment. In the plastic bag process, the sauerkraut, containing the fermentation liquor, is placed in plastic bags and chemical additives (benzoic acid, sorbic acid, and sodium bisulfite) introduced as preservatives. The bags are sealed and refrigerated. Small quantities, approximately 10 percent of the production, are packaged in glass containers, which may be preserved by heating or using chemical additives.

Sauces -

A typical sauce production operation involves the mixture of several ingredients, often including salts, vinegars, sugar, vegetables, and various spices. The mixture is allowed to ferment for a period of time, sealed in containers, and pasteurized to prevent further fermentation. The production processes for Worcestershire sauce and hot pepper sauces are briefly described as examples of sauce production.

The name "Worcestershire Sauce" is now a generic term for a type of food condiment that originated in India. In the preparation of the true sauce, a mixture of vinegar, molasses, sugar, soy, anchovies, tamarinds, eschalots, garlic, onions, and salt is prepared and well mixed. Spices, flavorings, and water are added and the mixture transferred to an aging tank, sealed, and allowed to mature and ferment over a period of time. The fermenting mixture is occasionally agitated to ensure proper blending. After fermentation is complete, the mixture to remain in the liquid. The product is then pasteurized prior to bottling to prevent further fermentation. Following bottling, the product is cooled, labeled, and packaged.

Hot sauce or pepper sauce is a generic name given to a large array of bottled condiments produced by several manufacturers in the U. S. The hot peppers, usually varieties of *Capsicum* annum and *Capsicum frutescens*, give the products their heat and characteristic flavor; vinegar is the usual liquid medium. Manufacturing processes vary by producer; however, in most, the harvested

hot peppers are washed and either ground for immediate use or stored whole in brine for several months until processed. In processing, the whole peppers are ground, salt and vinegar added, and the mixture passed through a filter to remove seeds and skin. The end-product, a stable suspension of the pulp from the pepper, vinegar, and salt, is then bottled, labeled, and stored for shipment.

Salad Dressings -

Salad dressings (except products modified in calories, fat, or cholesterol) are typically made up of oil, vinegar, spices, and other food ingredients to develop the desired taste. These dressings are added to many types of foods to enhance flavor. There are U. S. FDA Standards of Identity for three general classifications of salad dressings: mayonnaise, spoonable (semisolid) salad dressing, and French dressing. All other dressings are nonstandardized and are typically referred to as "pourable".

Mayonnaise is a semisolid emulsion of edible vegetable oil, egg yolk or whole egg, acidifying ingredients (vinegar, lemon or lime juice), seasonings (e. g., salt, sweeteners, mustard, paprika), citric acid, malic acid, crystallization inhibitors, and sequestrants to preserve color and flavor. Mayonnaise is an oil-in-water type emulsion where egg is the emulsifying agent and vinegar and salt are the principal bacteriological preservatives. The production process begins with mixing water, egg, and dry ingredients and slowly adding oil while agitating the mixture. Vinegar is then added to the mixture and, after mixing is complete, containers are filled, capped, labeled, and stored or shipped. Improved texture and uniformity of the final product is achieved through the use of colloidalizing or homogenizing machines.

Salad dressing is a spoonable (semisolid) combination of oil, cooked starch paste base, and other ingredients. During salad dressing production, the starch paste base is prepared by mixing starch (e. g., food starch, tapioca, wheat or rye flours) with water and vinegar. Optional ingredients include salt, nutritive carbohydrate sweeteners (e. g., sugar, dextrose, corn syrup, honey), any spice (except saffron and tumeric) or natural flavoring, monosodium glutamate, stabilizers and thickeners, citric and/or malic acid, sequestrants, and crystallization inhibitors. To prepare the salad dressing, a portion of the starch paste and other optional ingredients, except the oil, are blended and then the oil is slowly added to form a "preemulsion". When one-half of the oil is incorporated, the remainder of the starch paste is added at the same rate as the oil. After all of the starch paste and oil have been added, the mixture continues to blend until the ingredients are thoroughly mixed and then the mixture is milled to a uniform consistency. The salad dressing is placed into containers that are subsequently capped, labeled, and stored or shipped.

Liquid dressings, except French dressing, do not have a FDA Standard of Identity. They are pourable products that contain vegetable oil as a basic ingredient. Dressings may also contain catsup, tomato paste, vinegars, cheese, sherry, spices, and other natural ingredients. Liquid dressings are packaged either as separable products with distinct proportions of oil and aqueous phases or as homogenized dressings that are produced by the addition of stabilizers and emulsifiers. The homogenized dressings are then passed through a homogenizer or colloidalizing machine prior to bottling.

9.8.3.3 Emissions And Controls⁴

No source tests have been performed to quantify emissions resulting from the production of pickles, sauerkraut, sauces, or salad dressings. For most of these industries, processes are conducted in closed tanks or other vessels and would not be expected to produce significant emissions. For some products, in certain instances, the potential exists for emissions of particulate matter (PM) or odor (VOC).

Emissions of PM potentially could result from solids handling, solids size reduction, and cooking. If raw vegetables are transported directly from the field, the unloading of these vegetables could result in emissions of dust or vegetative matter. For those products that involve cooking or evaporative condensation in open vessels, PM emissions may be produced by condensation of vapors and may be in the low-micrometer or submicrometer particle-size range.

The VOC emissions are most usually associated with thermal processing steps (e. g., cooking or evaporative condensation) or other processing steps performed in open vessels. Thermal processing steps conducted in closed vessels generally do not result in VOC emissions. Gaseous compounds emitted from those steps conducted in open vessels may contain malodorous VOC.

Because no emission data are available that quantify any VOC, HAP, or PM emissions from any of these industries, emission factors cannot be developed.

A number of VOC and particulate emission control techniques are potentially available to these industries. These include the traditional approaches of wet scrubbers, dry sorbants, and cyclones. No information is available on controls actually used in these industries. The controls discussed in this section are ones that theoretically could be used. The applicability of controls and the specific type of control device or combination of devices would vary from facility to facility depending upon the particular nature of the emissions and the pollutant concentration in the gas stream.

For general industrial processes, control of VOC from a gas stream can be accomplished using one of several techniques but the most common methods are absorption, adsorption, and afterburners. Absorptive methods encompass all types of wet scrubbers using aqueous solutions to absorb the VOC. The most common scrubber systems are packed columns or beds, plate columns, spray towers, or other types of towers. Adsorptive methods could include one of four main adsorbents: activated carbon, activated alumina, silica gel, or molecular sieves; activated carbon is the most widely used for VOC control. Afterburners may be either thermal incinerators or catalytic combustors.

Particulate control commonly employs methods such as venturi scrubbers, dry cyclones, wet or dry electrostatic precipitators (ESPs), or dry filter systems. The most common controls are likely to be the venturi scrubbers or dry cyclones. Wet or dry ESPs could be used depending upon the particulate loading of the gas stream.

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- 1. 1987 Census of Manufacturers, MC87-1-20-C, Industries Series, Preserved Fruits And Vegetables.
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9.9 Grain Processing

- 9.9.1 Grain Elevators And Processes
- 9.9.2 Cereal Breakfast Food
- 9.9.3 Pet Food
- 9.9.4 Alfalfa Dehydration
- 9.9.5 Pasta Manufacturing
- 9.9.6 Bread Baking
- 9.9.7 Corn Wet Milling

9.9.1 Grain Elevators And Processes

[Work In Progress]

The recommended interim AP-42 Section on Grain Elevators And Processes is available either through the Technology Transfer Network Bulletin Board System (TTN BBS) of EPA's Office Of Air Quality Planning And Standards or from the Emission Factor And Inventory Group's Fax CHIEF service.

The BBS can be accessed with a computer and modem at (919) 541-5407. The interim Section is found on the BBS in the "Q&A's/Policies/Recommendations" area under the "AP-42/EF Guidance" area of the "Clearinghouse For Emission Inventories And Factors" technical area.

The interim Section can be obtained also from the *Fax CHIEF* service by calling (919) 541-0548 or -5626 from the telephone handset of a facsimile machine and following the directions provided to request a document.

For assistance with either of these procedures, call the *Info CHIEF* help desk, (919) 541-5285, between 9:00 am and 4:00 pm Eastern time, Tuesday through Friday.

The interim emission factors for Grain Elevators And Processes are subject to change pending completion of emission source testing being conducted in early 1996.

9.9.2 Cereal Breakfast Food

9.9.2.1 General¹

Breakfast cereal products were originally sold as milled grains of wheat and oats that required further cooking in the home prior to consumption. In this century, due to efforts to reduce the amount of in-home preparation time, breakfast cereal technology has evolved from the simple procedure of milling grains for cereal products that require cooking to the manufacturing of highly sophisticated ready-to-eat products that are convenient and quickly prepared.

9.9.2.2 Process Description¹⁻³

Breakfast cereals can be categorized into traditional (hot) cereals that require further cooking or heating before consumption and ready-to-eat (cold) cereals that can be consumed from the box or with the addition of milk. The process descriptions in this section were adapted primarily from reference 3 and represent generic processing steps. Actual processes may vary considerably between plants, even those manufacturing the same type of cereal.

Traditional Cereals -

Traditional cereals are those requiring cooking or heating prior to consumption and are made from oats, farina (wheat), rice, and corn. Almost all (99 percent) of the traditional cereal market are products produced from oats (over 81 percent) and farina (approximately 18 percent). Cereals made from rice, corn (excluding corn grits), and wheat (other than farina) make up less than 1 percent of traditional cereals.

<u>Oat cereals</u>. The three types of oat cereals are old-fashioned oatmeal, quick oatmeal, and instant oatmeal. Old-fashioned oatmeal is made of rolled oat groats (dehulled oat kernels) and is prepared by adding water and boiling for up to 30 minutes. Quick oat cereal consists of thinner flakes made by rolling cut groats and is prepared by cooking for 1 to 15 minutes. Instant oatmeal is similar to quick oats but with additional treatments, such as the incorporation of gum to improve hydration; hot water is added but no other cooking is required. The major steps in the production of traditional oat cereal include grain receiving, cleaning, drying, hulling, groat processing, steaming, and flaking. Figure 9.9.2-1 is a generic process flow diagram for traditional oat cereal production.

Oats arrive at the mill via bulk railcar or truck and are sampled to ensure suitable quality for milling. Once the grain is deemed acceptable, it is passed over a receiving separator to remove coarse and fine material and binned according to milling criteria. Raw grain handling and processing is discussed in AP-42 Section 9.9.1, Grain Elevators and Processes.

Cleaning removes foreign material, such as dust, stems, and weed seeds, and oats that are unsuitable for milling. The cleaning process utilizes several devices to take advantage of particular physical properties of the grain. For example, screens utilize the overall size of the grain, aspirators and gravity tables utilize grain density, and discs with indent pockets and/or indent cylinders utilize the grain length or shape. After completing the cleaning process, the grain is called clean milling oats or green oats.

In the hulling process, most facilities use the impact huller, which separates the hull from the groat by impact, rather than traditional stone hulling. The groat is the portion of the oat that remains

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Figure 9.9.2-1. Traditional oat cereal production.

after the hull has been removed and is the part processed for human consumption. In impact hulling, the oats are fed through a rotating disc and flung out to strike the wall of the cylindrical housing tangentially, which separates the hull from the groat. The mixed material then falls to the bottom of the huller and is subjected to aspiration to separate the hulls from the groats. Impact hulling does not require predrying of the oats, although some facilities still use the traditional dry-pan process to impart a more nutty and less raw or green flavor to the final product. In the traditional dry-pan process, the green oats are dried in a stack of circular pans heated indirectly by steam to a surface temperature of 93° to 100°C (200° to 212°F). However, most facilities utilize enclosed vertical or horizontal grain conditioners or kilns to dry the groat after it has been separated from the hull because of the inefficiency of drying hulls. The grain conditioners have both direct (sparging) steam and indirect steam to heat the oats and impart flavor to the groats comparable to that resulting from the pan drying process.

After the groats are hulled, they are sized to separate the largest groats from the average-sized groats. The large groats are used to make the so-called old-fashioned oats and the other groats are cut using steel cutters to make quick oats. After groat processing, the groats (either whole or cut pieces, depending on the end product) typically pass through an atmospheric steamer located above the rollers. The groats must remain in contact with the live steam long enough to achieve a moisture content increase from 8 to 10 percent up to 10 to 12 percent, which is sufficient to provide satisfactory flakes when the whole or steel-cut groats are rolled.

The production of old-fashioned oat and quick oat flakes is the same, except for the starting material (old-fashioned oats start with whole groats and quick oats start with steel-cut groats). Both products are rolled between two cast iron equal-speed rolls in rigid end frames. Quick-oat products are rolled thinner than old-fashioned oats. Following rolling, the flakes are typically cooled and directed to packaging bins for holding.

Instant oatmeal is processed similarly to quick oatmeal through the steaming stage. After the groats are steamed, they are rolled thinner than those of quick oatmeal. The final product, along with specific amounts of hydrocolloid gum, salt, and other additives, is packaged into premeasured individual servings. The most important difference between instant oatmeal and other oatmeal products is the addition of hydrocolloid gum, which replaces the natural oat gums that would be leached from the flakes during traditional cooking, thus accelerating hydration of the flakes.

The standard package for old-fashioned and quick oatmeal is the spirally wound two-ply fiber tube with a paper label. Folded cartons are also used to package old-fashioned and quick oatmeal. Most of the instant hot cereals are packed in individual, single-serving pouches.

<u>Farina cereals</u>. Cereals made from farina are the second largest segment of the traditional hot cereal market, making up 18 percent. Farina is essentially wheat endosperm in granular form that is free from bran and germ. The preferred wheat for producing farina is hard red or winter wheat because the granules of endosperm for these types of wheat stay intact when hot cereals are prepared at home. As shown in Figure 9.9.2-2, farina cereal production begins with the receiving and milling of wheat. Information on wheat receiving, handling, and milling can be found in AP-42 Section 9.9.1, Grain Elevators and Processes. After milling, traditional farina cereals are packaged. Quick cook farina cereals are prepared primarily by the addition of disodium phosphate, with or without the further addition of a protcolytic enzyme. An instant (cook-in-the-bowl) product may be made by wetting and pressure-cooking the farina, then flaking and redrying prior to portion packaging.

<u>Wheat, rice, and corn cereals</u>. Other traditional cereals include whole wheat cereals, rice products, and corn products. These cereals make up less than 1 percent of the traditional cereal

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^aNot required for traditional or quick-cooking farina cereals.

Figure 9.9.2-2. Typical instant cook farina cereal production.

market. Whole wheat traditional cereals include milled, rolled, and cracked wheat products. Milled cereals are made in a hard wheat flour mill by drawing off medium-grind milled streams. Rice products have yet to find acceptance as a hot cereal, although rice can be ground into particles about the size of farina and cooked into a hot cereal resembling farina. Corn products include corn grits, cornmeal, corn flour, and corn bran. Corn grits are served primarily as a vegetable accompaniment to the main breakfast item and are not usually classified as a breakfast cereal although they can be consumed as such. Cornmeal, corn flour, and corn bran are used primarily as ingredients in the preparation of other foods and are not classified as breakfast cereals.

Ready-To-Eat Cereals -

In the United States, the word "cereal" is typically synonymous with a processed product that is suitable for human consumption with or without further cooking at home and is usually eaten at breakfast. Ready-to-eat cereals are typically grouped by cereal form rather than the type of grain used. These groups are flaked cereals, extruded flaked cereals, gun-puffed whole grains, extruded gun-puffed cereals, oven-puffed cereals, shredded whole grains, extruded shredded cereals, and granola cereals.

<u>Flaked cereals</u>. Flaked cereals are made directly from whole grain kernels or parts of kernels of corn, wheat, or rice and are processed in such a way as to obtain particles, called flaking grits, that form one flake each. The production of flaked cereals involves preprocessing, mixing, cooking, delumping, drying, cooling and tempering, flaking, toasting, and packaging. A general process flow diagram for cereal flake production is presented in Figure 9.9.2-3. Grain preparation, including receiving, handling, cleaning, and hulling, for flaked cereal production is similar to that discussed under traditional cereal production and in AP-42 Section 9.9.1, Grain Elevators and Processes. Before the grains can be cooked and made into flakes, they must undergo certain preprocessing steps. For corn, this entails dry milling regular field corn to remove the germ and the bran from the kernel, leaving chunks of endosperm. Wheat is preprocessed by steaming the kernels lightly and running them through a pair of rolls to break open the kernels. Care is taken not to produce flour or fine material. Rice does not require any special preprocessing steps for the production of rice flakes other than those steps involved in milling rough rice to form the polished head rice that is the normal starting material.

The corn, wheat, or rice grits are mixed with a flavor solution that includes sugar, malt, salt, and water. Weighed amounts of raw grits and flavor solution are then charged into rotating batch cookers. After the grits are evenly coated with the flavor syrup, steam is released into the rotating cooker to begin the cooking process. The cooking is complete when each kernel or kernel part has been changed from a hard, chalky white to a soft, translucent, golden brown. When the cooking is complete, rotation stops, the steam is turned off, and vents located on the cooker are opened to reduce the pressure inside the cooker to ambient conditions and to cool its contents. The exhaust from these vents may be connected to a vacuum system for more rapid cooling. After pressure is relieved, the cooker is uncapped and the rotation restarted. The cooked grits are then dumped onto moving conveyor belts located under the cooker discharge. The conveyors then pass through delumping equipment to break and size the loosely held-together grits into mostly single grit particles. Large volumes of air are typically drawn through the delumping equipment to help cool the product. It may be necessary to perform delumping and cooling in different steps to get proper separation of the grits so that they are the optimum size for drying; in this case, cooling is typically performed first to stop the cooking action and to eliminate stickiness from the grit surface. After cooking and delumping, the grits are metered in a uniform flow to the dryer. Drying is typically performed at temperatures below 121°C (250°F) and under controlled humidity, which prevents case hardening of the grit and greatly decreases the time needed for drying to the desired moisture level. After drying, the grits are cooled to ambient temperature, usually in an unheated section of the dryer. After they are cooled, the grits are tempered by holding them in large accumulating bins to allow the moisture



Figure 9.9.2-3. Process diagram for cereal flake production.¹

content to equilibrate between the grit particles as well as from the center of the individual particles to the surface. After tempering, the grits pass between pairs of very large metal rolls that press them into very thin flakes. Flakes are toasted by suspending them in a hot air stream, rather than by laying them onto a flat baking surface. The ovens, sloped from feed end to discharge end, are perforated on the inside to allow air flow. These perforations are as large as possible for good air flow but small enough so that flakes cannot catch in them. The toasted flakes are then cooled and sent to packaging.

Extruded flake cereals. Extruded flakes differ from traditional flakes in that the grit for flaking is formed by extruding mixed ingredients through a die and cutting pellets of the dough into the desired size. The steps in extruded flake production are preprocessing, mixing, extruding, drying, cooling and tempering, flaking, toasting, and packaging. Figure 9.9.2-4 presents a generic process flow diagram for the production of extruded flake cereals. The primary difference between extruded flake production and traditional flake production is that extruded flakes replace the cooking and delumping steps used in traditional flake production with an extruding step. The extruder is a long, barrel-like apparatus that performs several operations along its length. The first part of the barrel kneads or crushes the grain and mixes the ingredients together. The flavor solution may be added directly to the barrel of the extruder by means of a metering pump. Heat input to the barrel of the extruder near the feed point is kept low to allow the ingredients to mix properly before any cooking or gelatinization starts. Heat is applied to the center section of the extruder barrel to cook the ingredients. The die is located at the end of the last section, which is generally cooler than the rest of the barrel. The dough remains in a compact form as it extrudes through the die and a rotating knife slices it into properly-sized pellets. The remaining steps for extruded flakes (drying, cooling, flaking, toasting, and packaging) are the same as for traditional flake production.

Gun-puffed whole grain cereals. Gun-puffed whole grains are formed by cooking the grains and then subjecting them to a sudden large pressure drop. As steam under pressure in the interior of the grain seeks to equilibrate with the surrounding lower-pressure atmosphere, it forces the grains to expand quickly or "puff." Rice and wheat are the only types of grain used in gun-puffed whole grain production, which involves pretreatment, puffing, screening, drying, and cooling. A general process flow diagram is shown in Figure 9.9.2-5. Wheat requires pretreating to prevent the bran from loosening from the grain in a ragged, haphazard manner, in which some of the bran adheres to the kernels and other parts to be blown partially off the kernels. One form of pretreatment is to add 4 percent, by weight, of a saturated brine solution (26 percent salt) to the wheat. Another form of pretreatment, called pearling, removes part of the bran altogether before puffing. The only pretreatment required for rice is normal milling to produce head rice. Puffing can be performed with manual single-shot guns, automatic single-shot, automatic multiple-shot guns, or continuous guns. In manual single-shot guns, grain is loaded into the opening of the gun and the lid is closed and sealed. As the gun begins to rotate, gas burners heat the sides of the gun body causing the moisture in the grain to convert to steam. When the lid is opened, the sudden change in pressure causes the grain to puff. Automatic single-shot guns operate on the same principle, except that steam is injected directly into the gun body. Multiple-shot guns have several barrels mounted on a slowly rotating wheel so that each barrel passes the load and fire positions at the correct time. The load, steam, and fire process for any one barrel is identical to that of the single-shot gun. After the grain is puffed, it is screened and dried before it is packaged. The final product is very porous and absorbs moisture rapidly and easily so it must be packaged in materials that possess good moisture barrier qualities.

<u>Extruded gun-puffed cereals</u>. Extruded gun-puffed cereals use a meal or flour as the starting ingredient instead of whole grains. The dough cooks in the extruders and is then formed into the desired shape when extruded through a die. The extrusion process for gun-puffed cereals is similar to that for extruded flake production. After the dough is extruded, it is dried and tempered. It then undergoes the same puffing and final processing steps as described for whole grain gun-puffed cereals.



Figure 9.9.2-4. Process diagram for extruded flake production.¹

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Figure 9.9.2-5. Gun-puffed whole grain production.¹

<u>Oven-puffed cereals</u>. Oven-puffed cereals are made almost exclusively using whole-grain rice or corn, or mixtures of these two grains, because rice and corn inherently puff in the presence of high heat and the proper moisture content. The grains are mixed with sugar, salt, water, and malt and then pressure-cooked. After cooking, the grain is conveyed through a cooling and sizing operation. After cooling and sizing, the kernels are dried and tempered. The kernels are then passed through flaking rolls to flatten them slightly. The kernels are dried again and then oven-puffed, which requires a proper balance between kernel moisture content and oven temperature. After puffing, the cereal is cooled, fortified with vitamins (if necessary), and frequently treated with antioxidants to preserve freshness. The final product is then packaged.

Whole-grain shredded cereals. Wheat (white wheat) is primarily used to produce shredded whole grains. The steps involved in producing whole-grain shredded cereal are grain cleaning, cooking, cooling and tempering, shredding, biscuit formation, biscuit baking, and packaging. A generic process flow diagram for shredded cereal production is presented in Figure 9.9.2-6. Cooking is typically performed in batches with excess water at temperatures slightly below the boiling point at atmospheric pressure. Cooking vessels usually have horizontal baskets big enough to hold 50 bushels of raw wheat. Steam is injected directly into the water to heat the grain. After the cooking cycle is completed, the water is drained from the vessel and the cooked wheat is dumped and conveyed to cooling units, which surface-dry the wheat and reduce the temperature to ambient levels, thus stopping the cooking process. After the grain is cooled, it is placed in large holding bins and allowed to temper. The shredding process squeezes the wheat kernels between one roll with a smooth surface and another roll with a grooved surface. A comb is positioned against the grooved roll and the comb teeth pick the wheat shred from the groove. There are many variations in the grooved roll. After the shreds are produced, they fall in layers onto a conveyer moving under the rolls. After the web of many layers of shreds reaches the end of the shredder, it is fed through a cutting device to form the individual biscuits. The edges of the cutting device are dull, rather than sharp, so that the cutting action compresses the edges of the biscuit together to form a crimped joint, which holds the shreds together in biscuit form. After the individual biscuits are formed, they are baked in a band or continuous conveyor-belt oven. After the biscuits are baked and dried, they are ready for packaging.

<u>Extruded shredded cereals</u>. Extruded shredded cereals are made in much the same way as whole-grain shredded cereals except that extruded shredded cereals use a meal or flour as a raw material instead of whole grains. Raw grains include wheat, corn, rice, and oats, and, because the grains are used in flour form, they can be used alone or in mixtures. The steps involved in extruded shredded cereal production are grain preprocessing (including grain receiving, handling, and milling), mixing, extruding, cooling and tempering, shredding, biscuit formation, baking, drying, and packaging. The preprocessing, mixing, extruding, and cooling and tempering steps are the same as those discussed for other types of cereal. Shredding, biscuit formation, baking, drying, and packaging are the same as for whole-grain shredded cereal. Extruded shredded cereals are typically made into small, bite-size biscuits, instead of the larger biscuits of whole-grain shredded wheat.

<u>Granola cereals</u>. Granola cereals are ready-to-eat cereals that are prepared by taking regular, old-fashioned whole-rolled oats or quick-cooking oats and mixing them with other ingredients, such as nut pieces, coconut, brown sugar, honey, malt extract, dried milk, dried fruits, water, cinnamon, nutmeg, and vegetable oil. This mixture is then spread in a uniform layer onto the band of a continuous dryer or oven. The toasted layer is then broken into chunks.

Packaging -

The package materials for ready-to-eat breakfast cereals include printed paperboard cartons, protective liners, and the necessary adhesives. The cartons are printed and produced by carton suppliers and are delivered, unfolded and stacked on pallets, to the breakfast cereal manufacturers.


Figure 9.9.2-6. Whole grain shredded cereal production.

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The liners, also supplied by outside sources, must be durable and impermeable to moisture or moisture vapor. However, cereals that are not hygroscopic and/or retain satisfactory texture in moisture equilibrium with ambient atmosphere do not require moisture-proof liners. The most common type of liners used today are made of high-density polyethylene (HDPE) film. The adhesives used in cereal packaging are water-based emulsions and hot melts. The cereal industry is the second largest user of adhesives for consumer products. Several variations of packaging lines may be used in the ready-to-eat breakfast cereal industry, including lines that fill the liners either before or after they have been inserted into the carton and lines that utilize more manual labor and less automated equipment.

9.9.2.3 Emissions And Controls

Air emissions may arise from a variety of sources in breakfast cereal manufacturing. Particulate matter (PM) emissions result mainly from solids handling and mixing. For breakfast cereal manufacturing, PM emissions occur during the milling and processing of grain, as the raw ingredients are dumped, weighed, and mixed, as the grains are hulled, and possibly during screening, drying, and packaging. Emission sources associated with grain milling and processing include grain receiving, precleaning and handling, cleaning house separators, milling, and bulk loading. Applicable emission factors for these processes are presented in AP-42 Section 9.9.1, Grain Elevators and Processes. There are no data on PM emissions from mixing of ingredients or packaging for breakfast cereal production.

Volatile organic compound (VOC) emissions may potentially occur at almost any stage in the production of breakfast cereal, but most usually are associated with thermal processing steps, such as drying, steaming, heat treatment, cooking, toasting, extruding, and puffing. Adhesives used during packaging of the final product may also be a source of VOC emissions. No information is available, however, on any VOC emissions resulting from these processes of breakfast cereal manufacturing.

Control technology to control PM emissions from breakfast cereal manufacturing is similar to that discussed in AP-42 Section 9.9.1, Grain Elevators and Processes. Because of the operational similarities, emission control methods are similar in most grain milling and processing plants. Cyclones or fabric filters are often used to control emissions from grain handling operations (e. g., unloading, legs, cleaners, etc.) and also from other processing operations. Fabric filters are used extensively in flour mills. However, certain operations within milling operations are not amenable to the use of these devices and alternatives are needed. Wet scrubbers, for example, are applied where the effluent gas stream has a high moisture content. No information exists for VOC emission control technology for breakfast cereal manufacturing.

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9.9.3 Pet Food

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9.9.4 Alfalfa Dehydrating

9.9.4.1 General¹⁻²

Dehydrated alfalfa is a meal product resulting from the rapid drying of alfalfa by artificial means. Alfalfa meal is processed into pellets for use in chicken rations, cattle feed, hog rations, sheep feed, turkey mash, and other formula feeds. It is important for its protein content, growth and reproductive factors, pigmenting xanthophylls, and vitamin contributions.

9.9.4.2 Process Description¹⁻⁵

A schematic of a generalized alfalfa dehydrator plant is given in Figure 9.9.4-1. Standing alfalfa is windrowed in the field to allow wilting to reduce moisture to an acceptable level balancing energy requirements, trucking requirements, and dehydrator capacity while maintaining the alfalfa quality and leaf quantity. The windrowed alfalfa is then chopped and hauled to the dehydration plant. The truck dumps the chopped alfalfa (wet chops) onto a self-feeder, which carries it into a direct-fired rotary drum. Within the drum, the wet chops are dried from an initial moisture content of about 30 to 70 percent (by weight, wet basis) to about 6 to 12 percent. Typical combustion gas temperatures within the gas-fired drum range from 154° to 816° C (300° to 1500° F) at the inlet to 60° to 95° C (140° to 210° F) at the outlet.

From the drying drum, the dry chops are pneumatically conveyed into a primary cyclone that separates them from the high-moisture, high-temperature exhaust stream. From the primary cyclone, the chops are fed into a hammermill, which grinds the dry chops into a meal. The meal is pneumatically conveyed from the hammermill into a meal collector cyclone in which the meal is separated from the airstream and discharged into a holding bin. The exhaust is recycled to a bag filter (baghouse). The meal is then fed into a pellet mill where it is steam conditioned and extruded into pellets.

From the pellet mill, the pellets are either pneumatically or mechanically conveyed to a cooler, through which air is drawn to cool the pellets and, in some cases, remove fines. Fines are more commonly removed using shaker screens located ahead of or following the cooler, with the fines being conveyed back into the meal collector cyclone, meal bin, or pellet mill. Cyclone separators may be employed to separate entrained fines in the cooler exhaust and to collect pellets when the pellets are pneumatically conveyed from the pellet mill to the cooler.

Following cooling and screening, the pellets are transferred to bulk storage. Dehydrated alfalfa is most often stored and shipped in pellet form, although the pellets may also be ground in a hammermill and shipped in meal form. When the finished or ground pellets are pneumatically or mechanically transferred to storage or loadout, additional cyclones may be used for product airstream separation.

9.9.4.3 Emissions And Controls^{1-3,5-7}

Particulate matter (PM) is the primary pollutant emitted from alfalfa dehydrating plants, although some odors may arise from the organic volatiles driven off during drying and pellet formation. The major source of PM emissions is the primary cyclone following the dryer drum.

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Lesser emission sources include the downstream cyclone separators and the bagging and loading operations.

Emission factors for various dryer types utilized in alfalfa dehydrating plants are given in Table 9.9.4-1. Note that, although these sources are common to many plants, there will be considerable variation from the generalized flow diagram in Figure 9.9.4-1 depending on the desired nature of the product, the physical layout of the plant, and the modifications made for air pollution control.

Table 9.9.4-1. EMISSION FACTORS FOR ALFALFA DEHYDRATION^a

	Particulate (PM)			
Source	Filterable	Condensible	VOC	Ref.
Triple-pass dryer cyclone				
- Gas-fired (SCC 3-02-001-11)	4.8	1.0	ND	8-9
- Coal-fired ^b (SCC 3-02-001-12)	7.5	ND	ND	13
Single-pass dryer cyclone				
- Gas-fired (SCC 3-02-001-15)	4.1	0.65	ND	10-11
- Wood-fired (SCC 3-02-001-17)	3.1	1.3	ND	12,14
Meal collector cyclone (SCC 3-02-001-03)	ND	ND	NA	
- Bag filter				
Pellet collector cyclone (SCC 3-02-001-07)	ND	ND	ND	
Pellet cooler cyclone (SCC 3-02-001-04)	ND	ND	NA	
Storage bin cyclone (SCC 3-02-001-20)	ND	ND	NA	

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^a Emission factor units are lb/ton of finished pellet produced, unless noted. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = No data.
 NA = Not applicable,

^b Emission factor based on quantity of dried alfalfa to hammermill.

Air pollution control (and product recovery) is accomplished in alfalfa dehydrating plants in a variety of ways. A simple, yet effective technique is the proper maintenance and operation of the alfalfa dehydrating equipment. Particulate emissions can be reduced significantly if the feeder discharge rates are uniform, if the dryer furnace is operated properly, if proper airflows are employed in the cyclone collectors, and if the hammermill is well maintained and not overloaded. It is especially important in this regard not to overdry and possibly burn the chops as this results in the generation of smoke and increased fines in the grinding and pelletizing operations.

Equipment modification provides another means of particulate control. Existing cyclones can be replaced with more efficient cyclones and concomitant air flow systems. In addition, the furnace and burners can be modified or replaced to minimize flame impingement on the incoming green chops.

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In plants where the hammermill is a production bottleneck, a tendency exists to overdry the chops to increase throughput, which results in increased emissions. Adequate hammermill capacity can reduce this practice. Recent improvements in process technique and emission control technology have reduced particulate emissions from dehydration facilities. Future technology should contribute to further reductions in particulate emissions.

Secondary control devices can be employed on the cyclone collector exhaust streams. Generally, this practice has been limited to the installation of secondary cyclones or fabric filters on the meal collector, pellet collector or pellet cooler cyclones. Primary cyclones are not controlled by fabric filters because of the high moisture content in the resulting exhaust stream. Medium energy wet scrubbers are effective in reducing particulate emissions from the primary cyclones, but have only been installed at a few plants.

Some plants employ cyclone effluent recycle systems for particulate control. One system skims off the particulate-laden portion of the primary cyclone exhaust and returns it to the alfalfa dryer. Another system recycles a large portion of the meal collector cyclone exhaust back to the hammermill. Both systems can be effective in controlling particulates but may result in operating problems, such as condensation in the recycle lines and plugging or overheating of the hammermill.

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9.9.5 Pasta Manufacturing

9.9.5.1 General¹⁻²

Although pasta products were first introduced in Italy in the 13th century, efficient manufacturing equipment and high-quality ingredients have been available only since the 20th century. Prior to the industrial revolution, most pasta products were made by hand in small shops. Today, most pasta is manufactured by continuous, high capacity extruders, which operate on the auger extrusion principle in which kneading and extrusion are performed in a single operation. The manufacture of pasta includes dry macaroni, noodle, and spaghetti production.

9.9.5.2 Process Description¹⁻²

Pasta products are produced by mixing milled wheat, water, eggs (for egg noodles or egg spaghetti), and sometimes optional ingredients. These ingredients are typically added to a continuous, high capacity auger extruder, which can be equipped with a variety of dies that determine the shape of the pasta. The pasta is then dried and packaged for market.

Raw Materials -

Pasta products contain milled wheat, water, and occasionally eggs and/or optional ingredients. Pasta manufacturers typically use milled durum wheat (semolina, durum granulars, and durum flour) in pasta production, although farina and flour from common wheat are occasionally used. Most pasta manufacturers prefer semolina, which consists of fine particles of uniform size and produces the highest quality pasta product. The water used in pasta production should be pure, free from offflavors, and suitable for drinking. Also, since pasta is produced below pasteurization temperatures, water should be used of low bacterial count. Eggs (fresh eggs, frozen eggs, dry eggs, egg yolks, or dried egg solids) are added to pasta to make egg noodles or egg spaghetti and to improve the nutritional quality and richness of the pasta. Small amounts of optional ingredients, such as salt, celery, garlic, and bay leafs, may also be added to pasta to enhance flavor. Disodium phosphate may be used to shorten cooking time. Other ingredients, such as gum gluten, glyceryl monostearate, and egg whites, may also be added. All optional ingredients must be clearly labeled on the package.

Wheat Milling -

Durum wheat is milled into semolina, durum granular, or durum flour using roll mills. Semolina milling is unique in that the objective is to prepare granular middlings with a minimum of flour production. Grain milling is discussed in AP-42 Section 9.9.1, Grain Elevators and Processes. After the wheat is milled, it is mixed with water, eggs, and any other optional ingredients.

Mixing -

In the mixing operation, water is added to the milled wheat in a mixing trough to produce dough with a moisture content of approximately 31 percent. Eggs and any optional ingredients may also be added. Most modern pasta presses are equipped with a vacuum chamber to remove air bubbles from the pasta before extruding. If the air is not removed prior to extruding, small bubbles will form in the pasta which diminish the mechanical strength and give the finished product a white, chalky appearance.

Extruding -

After the dough is mixed, it is transferred to the extruder. The extrusion auger not only forces the dough through the die, but it also kneads the dough into a homogeneous mass, controls the rate of production, and influences the overall quality of the finished product. Although construction and dimension of extrusion augers vary by equipment manufacturers, most modern presses have sharp-edged augers that have a uniform pitch over their entire length. The auger fits into a grooved extrusion barrel, which helps the dough move forward and reduces friction between the auger and the inside of the barrel. Extrusion barrels are equipped with a water cooling jacket to dissipate the heat generated during the extrusion process. The cooling jacket also helps to maintain a constant extrusion temperature, which should be approximately $51^{\circ}C$ ($124^{\circ}F$). If the dough is too hot (above $74^{\circ}C$ [$165^{\circ}F$]), the pasta will be damaged.

Uniform flow rate of the dough through the extruder is also important. Variances in the flow rate of the dough through the die cause the pasta to be extruded at different rates. Products of nonuniform size must be discarded or reprocessed, which adds to the unit cost of the product. The inside surface of the die also influences the product appearance. Until recently, most dies were made of bronze, which was relatively soft and required repair or periodic replacement. Recently, dies have been improved by fitting the extruding surface of the die with Teflon[®] inserts to extend the life of the dies and improve the quality of the pasta.

Drying -

Drying is the most difficult and critical step to control in the pasta production process. The objective of drying is to lower the moisture content of the pasta from approximately 31 percent to 12 to 13 percent so that the finished product will be hard, retain its shape, and store without spoiling. Most pasta drying operations use a preliminary drier immediately after extrusion to prevent the pasta from sticking together. Predrying hardens the outside surface of the pasta while keeping the inside soft and plastic. A final drier is then used to remove most of the moisture from the product.

Drying temperature and relative humidity increments are important factors in drying. Since the outside surface of the pasta dries more rapidly than the inside, moisture gradients develop across the surface to the interior of the pasta. If dried too quickly, the pasta will crack, giving the product a poor appearance and very low mechanical strength. Cracking can occur during the drying process or as long as several weeks after the product has left the drier. If the pasta is dried too slowly, it tends to spoil or become moldy during the drying process. Therefore, it is essential that the drying cycle be tailored to meet the requirements of each type of product. If the drying cycle has been successful, the pasta will be firm but also flexible enough so that it can bend to a considerable degree before breaking.

Packaging -

Packaging keeps the product free from contamination, protects the pasta from damage during shipment and storage, and displays the product favorably. The principal packaging material for noodles is the cellophane bag, which provides moisture-proof protection for the product and is used easily on automatic packaging machines, but is difficult to stack on grocery shelves. Many manufacturers utilize boxes instead of bags to package pasta because boxes are easy to stack, provide good protection for fragile pasta products, and offer the opportunity to print advertising that is easier to read than on bags.

EMISSION FACTORS

9.9.5.3 Emissions and Controls

Air emissions may arise from a variety of sources in pasta manufacturing. Particulate matter (PM) emissions result mainly from solids handling and mixing. For pasta manufacturing, PM emissions occur during the wheat milling process, as the raw ingredients are mixed, and possibly during packaging. Emission sources associated with wheat milling include grain receiving, precleaning/handling, cleaning house, milling, and bulk loading. Applicable emission factors for these processes are presented in AP-42 Section 9.9.1, Grain Elevators and Processes. There are no data for PM emissions from mixing of ingredients or packaging for pasta production.

Volatile organic compound (VOC) emissions may potentially occur at almost any stage in the production of pasta, but most usually are associated with thermal processing steps, such as pasta extruding or drying. No information is available on any VOC emissions due to the heat generated during pasta extrusion or drying.

Control of PM emissions from pasta manufacturing is similar to that discussed in AP-42 Section 9.9.1, Grain Elevators and Processes. Because of the operational similarities, emission control methods used in grain milling and processing plants are similar to those in grain elevators. Cyclones or fabric filters are often used to control emissions from the grain handling operations (e. g., unloading, legs, cleaners, etc.) and also from other processing operations. Fabric filters are used extensively in flour mills. However, certain operations within milling operations are not amenable to the use of these devices and alternatives are needed. Wet scrubbers, for example, may be applied where the effluent gas stream has a high moisture content.

References for Section 9.9.5

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9.9.6 Bread Baking

[Work In Progress]

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9.9.6 Bread Baking

USEPA Recommendation for Estimating VOC Emissions from Bread Bakeries

The Emissions Inventory Branch recommends the equation given in "Alternative Control Technology Document for Bakery Oven Emissions" (EPA 453/R-92-017, December 1992) for estimating VOC emissions from yeast-raised bread baking point sources. The equation is:

VOC E.F. = 0.95Yi+0.195ti-0.51S-0.86ts+1.90

where

VOC E.F.	= pounds VOC per ton of baked bread
Yi	= initial baker's percent of yeast
ti	= total yeast action time in hours
S	= final (spike) baker's percent of yeast
ts	= spiking time in hours

This equation will be incorporated into a future revision of AP-42 section 9.9.6. Full details on the derivation and use of the equation are contained in the ACT document cited above. Copies of the ACT document are available - as supplies permit - from the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711. It is also available for \$27.00 (stock number PB93-157618) from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161, phone (800) 553-6847.

9.9.7 Corn Wet Milling

9.9.7.1 General¹

Establishments in corn wet milling are engaged primarily in producing starch, syrup, oil, sugar, and byproducts such as gluten feed and meal, from wet milling of corn and sorghum. These facilities may also produce starch from other vegetables and grains, such as potatoes and wheat. In 1994, 27 corn wet milling facilities were reported to be operating in the United States.

9.9.7.2 Process Description¹⁻⁴

The corn wet milling industry has grown in its 150 years of existence into the most diversified and integrated of the grain processing industries. The corn refining industry produces hundreds of products and byproducts, such as high fructose corn syrup (HFCS), corn syrup, starches, animal feed, oil, and alcohol.

In the corn wet milling process, the corn kernel (see Figure 9.9.7-1) is separated into 3 principal parts: (1) the outer skin, called the bran or hull; (2) the germ, containing most of the oil; and (3) the endosperm (gluten and starch). From an average bushel of corn weighing 25 kilograms (kg) (56 pounds [lb]), approximately 14 kg (32 lb) of starch is produced, about 6.6 kg (14.5 lb) of feed and feed products, about 0.9 kg (2 lb) of oil, and the remainder is water. The overall corn wet milling process consists of numerous steps or stages, as shown schematically in Figure 9.9.7-2.

Shelled corn is delivered to the wet milling plant primarily by rail and truck and is unloaded into a receiving pit. The corn is then elevated to temporary storage bins and scale hoppers for weighing and sampling. The corn then passes through mechanical cleaners designed to remove unwanted material, such as pieces of cobs, sticks, and husks, as well as meal and stones. The cleaners agitate the kernels over a series of perforated metal sheets through which the smaller foreign materials drop. A blast of air blows away chaff and dust, and electromagnets remove bits of metal. Coming out of storage bins, the corn is given a second cleaning before going into "steep" tanks.

Steeping, the first step in the process, conditions the grain for subsequent milling and recovery of corn constituents. Steeping softens the kernel for milling, helps break down the protein holding the starch particles, and removes certain soluble constituents. Steeping takes place in a series of tanks, usually referred to as steeps, which are operated in continuous-batch process. Steep tanks may hold from 70.5 to 458 cubic meters (m³) (2,000 to 13,000 bushels [bu]) of corn, which is then submerged in a current of dilute sulfurous acid solution at a temperature of about 52°C (125°F). Total steeping time ranges from 28 to 48 hours. Each tank in the series holds corn that has been steeping for a different length of time.

Corn that has steeped for the desired length of time is discharged from its tank for further processing, and the tank is filled with fresh corn. New steeping liquid is added, along with recycled water from other mill operations, to the tank with the "oldest" corn (in steep time). The liquid is then passed through a series of tanks, moving each time to the tank holding the next "oldest" batch of corn until the liquid reaches the newest batch of corn.

Water drained from the newest corn steep is discharged to evaporators as so-called "light steepwater" containing about 6 percent of the original dry weight of grain. By dry-weight, the solids

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Figure 9.9.7-1. Various uses of corn.

in the steepwater contain 35 to 45 percent protein and are worth recovering as feed supplements. The steepwater is concentrated to 30 to 55 percent solids in multiple-effect evaporators. The resulting steeping liquor, or heavy steepwater, is usually added to the fibrous milling residue, which is sold as animal feed. Some steepwater may also be sold for use as a nutrient in fermentation processes.

The steeped corn passes through degerminating mills, which tear the kernel apart to free both the germ and about half of the starch and gluten. The resultant pulpy material is pumped through liquid cyclones to extract the germ from the mixture of fiber, starch, and gluten. The germ is subsequently washed, dewatered, and dried; the oil extracted; and the spent germ sold as corn oil meal or as part of corn gluten feed. More details on corn oil production are contained in Section 9.11.1, "Vegetable Oil Processing".

The product slurry passes through a series of washing, grinding, and screening operations to separate the starch and gluten from the fibrous material. The hulls are discharged to the feed house, where they are dried for use in animal feeds.

At this point, the main product stream contains starch, gluten, and soluble organic materials. The lower density gluten is separated from the starch by centrifugation, generally in 2 stages. A high-quality gluten, of 60 to 70 percent protein and 1.0 to 1.5 percent solids, is then centrifuged, dewatered, and dried for adding to animal feed. The centrifuge underflow containing the starch is passed to starch washing filters to remove any residual gluten and solubles.

The pure starch slurry is now directed into 1 of 3 basic finishing operations, namely, ordinary dry starch, modified starches, and corn syrup and sugar. In the production of ordinary dry starch, the starch slurry is dewatered with vacuum filters or basket centrifuges. The discharged starch cake has a moisture content of 35 to 42 percent and is further dewatered thermally in 1 of several types of dryers. The dry starch is then packaged or shipped in bulk, or a portion may be kept for use in making dextrin.

9.9.7-2 EMISSION FACTORS	
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Figure 9.9.7-2. Corn wet milling process flow diagram.¹⁻⁴ (Source Classification Codes in parentheses.)

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9.9.7-3

Modified starches are manufactured for various food and trade industries for which unmodified starches are not suitable. For example, large quantities of modified starches go into the manufacture of paper products as binding for the fiber. Modifying is accomplished in tanks that treat the starch slurry with selected chemicals, such as hydrochloric acid, to produce acid-modified starch; sodium hypochlorite, to produce oxidized starch; and ethylene oxide, to produce hydroxyethyl starches. The treated starch is then washed, dried, and packaged for distribution.

Across the corn wet milling industry, about 80 percent of starch slurry goes to corn syrup, sugar, and alcohol production. The relative amounts of starch slurry used for corn syrup, sugar, and alcohol production vary widely among plants. Syrups and sugars are formed by hydrolyzing the starch — partial hydrolysis resulting in corn syrup, and complete hydrolysis producing corn sugar. The hydrolysis step can be accomplished using mineral acids, enzymes, or a combination of both. The hydrolyzed product is then refined, which is the decolorization with activated carbon and the removal of inorganic salt impurities with ion exchange resins. The refined syrup is concentrated to the desired level in evaporators and is cooled for storage and shipping.

Dextrose production is quite similar to corn syrup production, the major difference being that the hydrolysis process is allowed to go to completion. The hydrolyzed liquor is refined with activated carbon and ion exchange resins, to remove color and inorganic salts, and the product stream is concentrated by evaporation to the 70 to 75 percent solids range. After cooling, the liquor is transferred to crystallizing vessels, where it is seeded with sugar crystals from previous batches. The solution is held for several days while the contents are further cooled and the dextrose crystallizes. After about 60 percent of the dextrose solids crystallize, they are removed from the liquid by centrifuges, are dried, and are packed for shipment.

A smaller portion of the syrup refinery is devoted to the production of corn syrup solids. In this operation, refined corn syrup is further concentrated by evaporation to a high dry substance level. The syrup is then solidified by rapid cooling and subsequently milled to form an amorphous crystalline product.

Ethanol is produced by the addition of enzymes to the pure starch slurry to hydrolyze the starch to fermentable sugars. Following hydrolysis, yeast is added to initiate the fermentation process. After about 2 days, approximately 90 percent of the starch is converted to ethanol. The fermentation broth is transferred to a still where the ethanol (about 50 vol%) is distilled. Subsequent distillation and treatment steps produce 95 percent, absolute, or denatured ethanol. More details on this ethanol production process, emissions, and emission factors is contained in Section 6.21, "Ethanol".

9.9.7.3 Emissions And Controls^{1-2,4-8}

The diversity of operations in corn wet milling results in numerous and varied potential sources of air pollution. It has been reported that the number of process emission points at a typical plant is well over 100. The main pollutant of concern in grain storage and handling operations in corn wet milling facilities is particulate matter (PM). Organic emissions (e. g., hexane) from certain operations at corn oil extraction facilities may also be significant. These organic emissions (and related emissions from soybean processing) are discussed in Section 9.11.1, "Vegetable Oil Processing". Other possible pollutants of concern are volatile organic compounds (VOC) and combustion products from grain drying, sulfur dioxide (SO₂) from corn wet milling operations, and organic materials from starch production. The focus here is primarily on PM sources for grain handling operations. Sources of VOC and SO₂ are identified, although no data are available to quantify emissions.

9	.9	.7	-4

EMISSION FACTORS

Emission sources associated with grain receiving, cleaning, and storage are similar in character to those involved in all other grain elevator operations, and other PM sources are comparable to those found in other grain processing plants as described in Section 9.9.1, "Grain Elevators And Processes". However, corn wet milling operations differ from other processes in that they are also sources of SO_2 and VOC emissions, as described below.

The corn wet milling process uses about 1.1 to 2.0 kg of SO₂ per megagram (Mg) of corn (0.06 to 0.11 lb/bu). The SO₂ is dissolved in process waters, but its pungent odor is present in the slurries, necessitating the enclosing and venting of the process equipment. Vents can be wet-scrubbed with an alkaline solution to recover the SO₂ before the exhaust gas is discharged to the atmosphere. The most significant source of VOC emissions, and also a source of PM emissions, from corn wet milling is the exhaust from the different drying processes. The starch modification procedures also may be sources of acid mists and VOC emissions, but data are insufficient to characterize or to quantify these emissions.

Dryer exhausts exhibit problems with odor and blue haze (opacity). Germ dryers emit a toasted smell that is not considered objectionable in most areas. Gluten dryer exhausts do not create odor or visible emission problems if the drying temperature does not exceed 427°C (800°F). Higher temperatures promote hot smoldering areas in the drying equipment, creating a burnt odor and a bluebrown haze. Feed drying, where steepwater is present, results in environmentally unacceptable odor if the drying temperature exceeds 427°C (800°F). Blue haze formation is a concern when drying temperatures are elevated. These exhausts contain VOC with acrid odors, such as acetic acid and acetaldehyde. Rancid odors can come from butyric and valeric acids, and fruity smells emanate from many of the aldehydes present.

The objectionable odors indicative of VOC emissions from process dryers have been reduced to commercially acceptable levels with ionizing wet-collectors, in which particles are charged electrostatically with up to 30,000 volts. An alkaline wash is necessary before and after the ionizing sections. Another approach to odor/VOC control is thermal oxidation at approximately 750°C (1382°F) for 0.5 seconds, followed by some form of heat recovery. This hot exhaust can be used as the heat source for other dryers or for generating steam in a boiler specifically designed for this type of operation. Incineration can be accomplished in conventional boilers by routing the dryer exhaust gases to the primary air intake. The limitations of incineration are potential fouling of the boiler air intake system with PM and derated boiler capacity because of low oxygen content. These limitations severely restrict this practice. At least 1 facility has attempted to use a regenerative system, in which dampers divert the gases across ceramic fill where exhaust heats the fumes to be incinerated. Incinerator size can be reduced 20 to 40 percent when some of the dryer exhaust is fed back into the dryer furnace. From 60 to 80 percent of the dryer exhaust may be recycled by chilling it to condense the water before recycling.

The PM emissions generated from grain receiving, handling, and processing operations at corn wet milling facilities can be controlled either by process modifications designed to prevent or inhibit emissions or by application of capture collection systems.

The fugitive emissions from grain handling operations generated by mechanical energy imparted to the dust, both by the operations themselves and by local air currents in the vicinity of the operations, can be controlled by modifying the process or facility to limit the generation of fugitive dust. The primary preventive measures used by facilities are construction and sealing practices that limit the effect of air currents, and minimizing grain free fall distances and grain velocities during handling and transfer. Some recommended construction and sealing practices that minimize emissions are: (1) enclosing the receiving area to the extent practicable; (2) specifying dust-tight cleaning and

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processing equipment; (3) using lip-type shaft seals at bearings on conveyor and other equipment housings; (4) using flanged inlets and outlets on all spouting, transitions, and miscellaneous hoppers; and (5) fully enclosing and sealing all areas in contact with products handled.

While preventive measures can reduce emissions, most facilities also require ventilation or capture/collection systems to reduce emissions to acceptable levels. Milling operations generally are ventilated, and some facilities use hood systems on all handling and transfer operations. The control devices typically used in conjunction with capture systems for grain handling and processing operations are cyclones (or mechanical collectors) and fabric filters. Both of these systems can achieve acceptable levels of control for many grain handling and processing sources. However, even though cyclone collectors can achieve acceptable performance in some scenarios, and fabric filters are highly efficient, both devices are subject to failure if not properly operated and maintained. Ventilation system malfunction, of course, can lead to increased emissions at the source.

Table 9.9.7-1 shows the filterable PM emission factors developed from the available data on several source/control combinations. Table 9.9.7-2 shows potential sources of VOC and SO_2 , although no data are available to characterize these emissions.

Table 9.9.7-1 (Metric And English Units). PARTICULATE MATTER EMISSION FACTORS FOR CORN WET MILLING OPERATIONS^a

EMISSION FACTOR RATING: E

		Filterab	le PM ^b
Emission Source	Type Of Control	kg/Mg	lb/ton
Grain receiving ^c (trucks) (SCC 3-02-007-51)	Fabric filter	0.016	0.033
Grain handling ^c (legs, belts, etc.) (SCC 3-02-007-52)	None	0.43	0.87
Grain cleaning ^d (SCC 3-02-007-53)	None	0.82	1.6
Grain cleaning ^d (SCC 3-02-007-53)	Cyclone	0.086	0.17
Starch storage bin ^e (SCC 3-02-014-07)	Fabric filter	0.0007	0.0014
Starch bulk loadout ^f (SCC 3-02-014-08)	Fabric filter	0.00025	0.00049
Gluten feed drying			
Direct-fired rotary dryers ^g (SCC 3-02-007-63)	Product recovery cyclone	0.13	0.27
Indirect-fired rotary dryers ^g (SCC 3-02-007-64)	Product recovery cyclone ^h	0.25	0.49
Starch drying			
Flash dryers ^j (SCC 3-02-014-10, -12)	Wet scrubber	0.29	0.59
Spray dryers ^k (SCC 3-02-014-11, -13)	Fabric filter	0.080	0.16
Gluten drying			
Direct-fired rotary dryers ^g (SCC 3-02-007-68)	Product recovery cyclone	0.13	0.27
Indirect-fired rotary dryers ^g (SCC 3-02-007-69)	Product recovery cyclone	0.25	0.49
Fiber drying (SCC 3-02-007-67)	ND	ND	ND
Germ drying (SCC 3-02-007-66)	ND	ND	ND
Dextrose drying (SCC 3-02-007-70)	ND	ND	ND
Degerminating mills (SCC 3-02-007-65)	ND	ND	ND
Milling (SCC 3-02-007-56)	ND	ND	ND

Table 9.9.7-1 (cont.).

- ^a For grain transfer and handling operations, factors are for an aspirated collection system of 1 or more capture hoods ducted to a particulate collection device. Because of natural removal processes, uncontrolled emissions may be overestimated. ND = no data. SCC = Source Classification Code.
- ^b Emission factors based on weight of PM, regardless of size, per unit weight of corn throughput unless noted.
- ^c Assumed to be similar to country grain elevators (see Section 9.9.1).
- ^d Assumed to be similar to country grain elevators (see Section 9.9.1). If 2 cleaning stages are used, emission factor should be doubled.
- ^e Reference 9.
- ^f Reference 9. Emission factor based on weight of PM per unit weight of starch loaded.
- ^g Reference 10. Type of material dried not specified, but expected to be gluten meal or gluten feed. Emission factor based on weight of PM, regardless of size, per unit weight of gluten meal or gluten feed produced.
- ^h Includes data for 4 (out of 9) dryers known to be vented through product recovery cyclones, and other systems are expected to have such cyclones. Emission factor based on weight of PM, regardless of size, per unit weight of gluten meal or gluten feed produced.
- ^j References 11-13. EMISSION FACTOR RATING: D. Type of material dried is starch, but whether the starch is modified or unmodified is not known. Emission factor based on weight of PM, regardless of size, per unit weight of starch produced.
- ^k Reference 14. Type of material dried is starch, but whether the starch is modified or unmodified is not known. Emission factor based on weight of PM, regardless of size, per unit weight of starch produced.

	Type Of	VC	C	SO ₂		
Emission Source	Control	kg/Mg	lb/ton	kg/Mg	lb/ton	
Steeping (SCC 3-02-007-61)	ND	ND	ND	ND	ND	
Evaporators (SCC 3-02-007-62)	ND	ND	ND	ND	ND	
Gluten feed drying (SCC 3-02-007-63, -64)	ND	ND	ND	ND	ND	
Germ drying (SCC 3-02-007-66)	ND	ND	ND	ND	ND	
Fiber drying (SCC 3-02-007-67)	ND	ND	ND	ND	ND	
Gluten drying (SCC 3-02-007-68, -69)	ND	ND	ND	ND	ND	
Starch drying (SCC 3-02-014-10, -11, -12, -13)	ND	ND	ND	ND	ND	
Dextrose drying (SCC 3-02-007-70)	ND	ND	ND	ND	ND	
Oil expelling/extraction (SCC 3-02-019-16)	ND	ND	ND	ND	ND	

Table 9.9.7-2 (Metric And English Units). EMISSION FACTORS FOR CORN WET MILLING OPERATIONS

ND = no data. SCC = Source Classification Code.

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- 12. No. 4 Starch Flash Dryer, Report No. I-7231-1, prepared by The Almega Corporation, Bensenville, IL, May 1993.
- 13. No. 1 Starch Flash Dryer, Report No. 86-177-3, prepared by Burns & McDonnell, Kansas City, MO, August 1986.
- 14. Starch Spray Dryer, Report No. 21511, prepared by Mostardi-Platt Associates, Inc., Bensenville, IL, August 1992.

9.10 Confectionery Products

- 9.10.1 Sugar Processing
- 9.10.2 Salted And Roasted Nuts and Seeds

9.10.1 Sugar Processing

- 9.10.1.1 Cane Sugar Processing
- 9.10.1.2 Beet Sugar Processing

9.10.1.1 Cane Sugar Processing

9.10.1.1.1 General¹⁻³

Sugar cane is burned in the field prior to harvesting to remove unwanted foliage as well as to control rodents and insects. Harvesting is done by hand or, where possible, by mechanical means.

After harvesting, the cane goes through a series of processing steps for conversion to the final sugar product. It is first washed to remove dirt and trash, then crushed and shredded to reduce the size of the stalks. The juice is next extracted by 1 of 2 methods, milling or diffusion. In milling, the cane is pressed between heavy rollers to squeeze out the juice; in diffusion, the sugar is leached out by water and thin juices. The raw sugar then goes through a series of operations including clarification, evaporation, and crystallization in order to produce the final product. The fibrous residue remaining after sugar extraction is called bagasse.

All mills fire some or all of their bagasse in boilers to provide power necessary in their milling operation. Some, having more bagasse than can be utilized internally, sell the remainder for use in the manufacture of various chemicals such as furfural.

9.10.1.1.2 Emissions^{2,3}

The largest sources of emissions from sugar cane processing are the openfield burning in the harvesting of the crop, and the burning of bagasse as fuel. In the various processes of crushing, evaporation, and crystallization, relatively small quantities of particulates are emitted. Emission factors for sugar cane field burning are shown in Table 2.5-2. Emission factors for bagasse firing in boilers are included in Section 1.8.

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9.10.1.2 Sugarbeet Processing

9.10.1.2.1 General¹⁻²

Sugarbeet processing is the production of sugar (sucrose) from sugarbeets. Byproducts of sugarbeet processing include pulp and molasses. Most of the molasses produced is processed further to remove the remaining sucrose. The pulp and most of the remaining molasses are mixed together, dried, and sold as livestock feed.

9.10.1.2.2 Process Description¹⁻⁴

Figures 9.10.1.2-1 and 9.10.1.2-2 are flow diagrams for a typical sugarbeet processing plant. Figure 9.10.1.2-1 shows preprocessing and livestock feed production operations, and Figure 9.10.1.2-2 shows the beet sugar production operations. Mechanically harvested sugarbeets are shipped to processing plants, where they are typically received by high-speed conveying and screening systems. The screening systems remove loose dirt from the beets and pinch the beet tops and leaves from the beet roots. The conveyors transport the beets to storage areas and then to the final cleaning and trash removal operations that precede the processing operations. The beets are usually conveyed to the final cleaning phase using flumes, which use water to both move and clean the beets. Although most plants use flumes, some plants use dry conveyors in the final cleaning stage. The disadvantage of flume conveying is that some sugar leaches into the flume water from damaged surfaces of the beets. The flumes carry the beets to the beet feeder, which regulates the flow of beets through the system and prevents stoppages in the system. From the feeder, the flumes carry the beets through several cleaning devices, which may include rock catchers, sand separators, magnetic metal separators, water spray nozzles, and trash catchers. After cleaning, the beets are separated from the water, usually with a beet wheel, and are transported by drag chain, chain and bucket elevator, inclined belt conveyor, or beet pump to the processing operations.

Sugarbeet processing operations comprise several steps, including diffusion, juice purification, evaporation, crystallization, dried-pulp manufacture, and sugar recovery from molasses. Descriptions of these operations are presented in the following paragraphs.

Prior to removal of the sucrose from the beet by diffusion, the cleaned and washed beets are sliced into long, thin strips, called cossettes. The cossettes are conveyed to continuous diffusers, in which hot water is used to extract sucrose from the cossettes. In one diffuser design, the diffuser is slanted upwards and conveys the cossettes up the slope as water is introduced at the top of the diffuser and flows countercurrent to the cossettes. The water temperature in the diffuser is typically maintained between 50° and 80°C (122° and 176°F). This temperature is dependant on several factors, including the denaturization temperature of the cossettes, the thermal behavior of the beet cell wall, potential enzymatic reactions, bacterial activity, and pressability of the beet pulp. Formalin, a 40 percent solution of formaldehyde, was sometimes added to the diffuser water as a disinfectant but is not used at the present time. Sulfur dioxide, chlorine, ammonium bisulfite, or commercial FDA-approved biocides are used as disinfectants. The sugar-enriched water that flows from the outlet of the diffuser is called raw juice and contains between 10 and 15 percent sugar. This raw juice proceeds to the juice purification operations. The processed cossettes, or pulp, leaving the diffuser are conveyed to the dried-pulp manufacture operations.



Figure 9.10.1.2-1. Preprocessing and livestock feed production operations at a sugarbeet processing plant. (Source Classification Code in parentheses.)



Figure 9.10.1.2-2. Sugar production operations at a sugarbeet processing plant. (Source Classification Code in parentheses.)

In the juice purification stage, non-sucrose impurities in the raw juice are removed so that the pure sucrose can be crystallized. First, the juice passes through screens to remove any small cossette particles. Then the mixture is heated to 80° to 85° C (176° to 185° F) and proceeds to the first carbonation tank. In some processes, the juice from the screen passes through a pre-limer, heater, and main limer prior to the first carbonation tank. In the first carbonation tank, milk of lime $[Ca(OH)_2]$ is added to the mixture to adsorb or adhere to the impurities in the mixture, and carbon dioxide (CO_2) gas is bubbled through the mixture to precipitate the lime as insoluble calcium carbonate crystals. Lime kilns are used to produce the CO_2 and lime used in carbonation; the lime is converted to milk of lime in a lime slaker. The small, insoluble crystals (produced during carbonation) settle out in a clarifier, after which the juice is again treated with CO_2 (in the second carbonation tank) to remove the remaining lime and impurities. The pH of the juice is lower during this second carbonation, causing large, easily filterable, calcium carbonate crystals to form. After filtration, a small amount of sulfur dioxide (SO_2) is added to the juice to inhibit reactions that lead to darkening of the juice. Most facilities purchase SO_2 as a liquid but a few facilities produce SO_2 by burning elemental sulfur in a sulfur stove. Following the addition of SO_2 , the juice (known as thin juice) proceeds to the evaporators.

The evaporation process, which increases the sucrose concentration in the juice by removing water, is typically performed in a series of five evaporators. Steam from large boilers is used to heat the first evaporator, and the steam from the water evaporated in the first evaporator is used to heat the second evaporator. This transfer of heat continues through the five evaporators, and as the temperature decreases (due to heat loss) from evaporator to evaporator, the pressure inside each evaporator is also decreased, allowing the juice to boil at the lower temperatures provided in each subsequent evaporator. Some steam is released from the first three evaporation, the percentage of sucrose in the "thick juice" is 50-65 percent. Crystalline sugars, produced later in the process, are added to the juice and dissolved in the high melter. This mixture is then filtered, yielding a clear liquid known as standard liquor, which proceeds to the crystallization operation.

Sugar is crystallized by low-temperature pan boiling. The standard liquor is boiled in vacuum pans until it becomes supersaturated. To begin crystal formation, the liquor is either "shocked" using a small quantity of powdered sugar or is "seeded" by adding a mixture of finely milled sugar and isopropyl alcohol. The seed crystals are carefully grown through control of the vacuum, temperature, feed-liquor additions, and steam. When the crystals reach the desired size, the mixture of liquor and crystals, known as massecuite or fillmass, is discharged to the mixer. From the mixer, the massecuite is poured into high-speed centrifugals, in which the liquid is centrifuged into the outer shell, and the crystals are left in the inner centrifugal basket. The sugar crystals are then washed with pure hot water and are sent to the granulator, which is a combination rotary drum dryer and cooler. Some facilities have separate sugar dryers and coolers, which are collectively called granulators. The wash water, which contains a small quantity of sucrose, is pumped to the vacuum pans for processing. After cooling, the sugar is screened and then either packaged or stored in large bins for future packaging.

The liquid that was separated from the sugar crystals in the centrifugals is called syrup. This syrup serves as feed liquor for the "second boiling" and is introduced back into the vacuum pans along with standard liquor and recycled wash water. The process is repeated once again, resulting in the production of molasses, which can be further desugarized using an ion exchange process called deep molasses desugarization. Molasses that is not desugarized can be used in the production of livestock feed or for other purposes.

Wet pulp from the diffusion process is another product of sugarbeet processing. The pulp is first pressed, typically in horizontal double-screw presses, to reduce the moisture content from about 95 percent

EMISSION FACTORS

to about 75 percent. The water removed by the presses is collected and used as diffusion water. After pressing, molasses is added to the pulp, which is then dried in a direct-fired horizontal rotating drum known as a pulp dryer. The pulp dryer, which can be fired by oil, natural gas, or coal, typically provides entrance temperatures between 482° and 927°C (900° and 1700°F). As the pulp is dried, the gas temperature decreases and the pulp temperature increases. The exit temperature of the flue gas is typically between 88° and 138°C (190° and 280°F). The resulting product is usually pelletized, cooled, and sold as livestock feed.

9.10.1.2.3 Emissions And Controls^{1,3-4}

Particulate matter (PM), combustion products, and volatile organic compounds (VOC) are the primary pollutants emitted from the sugarbeet processing industry. The pulp dryers, sugar granulators and coolers, sugar conveying and sacking equipment, lime kilns and handling equipment, carbonation tanks, sulfur stoves, evaporators, and boilers, as well as several fugitive sources are potential emission sources. Potential emissions from boilers are addressed in AP-42 Sections 1.1 through 1.4 (Combustion) and those from lime kilns are addressed in AP-42 Section 11.17, Lime Manufacturing. Potential sources of PM emissions include the pulp dryer, sugar granulators and coolers, sugar conveying and sacking equipment, sulfur stove, and fugitive sources. Fugitive sources include unpaved roads, coal handling, and pulp loading operations. Although most facilities purchase SO₂, a few facilities still use sulfur stoves. The sulfur stove is a potential source of SO2 emissions, and the pulp dryers may be a potential source of nitrogen oxides (NO_x), SO₂, CO₂, carbon monoxide (CO), and VOC. Evaporators may be a potential source of CO_2 , ammonia (NH₃), SO₂, and VOC emissions from the juice. However, only the first three of five evaporators (in a typical five-stage system) release exhaust gases, and the gases are used as a heat source for various process heaters before release to the atmosphere. Emissions from carbonation tanks are primarily water vapor but contain small quantities of NH₃, VOC, and may also include CO₂ and other combustion gases from the lime kiln. There are no emission test data available for ammonia emissions from carbonation tanks.

Particulate matter emissions from pulp dryers are typically controlled by a cyclone or multiclone system, sometimes followed by a secondary device such as a wet scrubber or fabric filter. Particulate matter emissions from granulators are typically controlled with wet scrubbers, and PM emissions from sugar conveying and sacking as well as lime dust handling operations are controlled by hood systems that duct the emissions to fabric filtration systems. Emissions from carbonation tanks and evaporators are not typically controlled.

Table 9.10.1.2-1 presents emission factors for filterable PM, PM-10, and condensible PM emissions from sugarbeet processing operations. Table 9.10.1.2-2 presents emission factors for volatile organic compounds (VOC), methane, NO_x , SO_2 , CO, and CO_2 emissions from sugarbeet processing operations, and Tables 9.10.1.2-3 and 9.10.1.2-4 present emission factors for organic pollutants emitted from coal-fired dryers, carbonation tanks, and first evaporators.

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Table 9.10.1.2-1. PARTICULATE MATTER EMISSION FACTORS FOR SUGARBEET PROCESSING OPERATIONS^a

			Filteral	ole PM				Conder	sible PM		
Source	Type of Control	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING	Total	EMISSION FACTOR RATING
Coal-fired pulp dryer ^b	None	4.4	D	ND		ND		ND		ND	
(SCC 3-02-016-01)	Multiclone	0.66 ^c	В	ND		ND		0.084 ^d	С	ND	
	Wet scrubber	0.49	D	ND		0.050 ^f	D	0.35 ^e	D	0.40 ^g	D
Natural gas-fired pulp dryer	Multiclone ^h	0.69	D	ND		ND		ND		ND	
(SCC 3-02-016-08)	Wet scrubber	0.19	D	ND		0.018 ^k	D	ND		ND	
Fuel oil-fired pulp dryer (SCC 3-02-016-05)	Cyclone	1.4	С	ND		0.24 ⁿ	С	0.076 ^m	С	0.32 ⁿ	С
	Dry scrubber and cyclone	1.1	D	0.83 ^p	D	0.24 ⁿ	С	ND		ND	
	Multiclone ^q	0.60	D	ND		ND		ND		ND	
Sugar granulator (SCC 3-02-016-58)	Mechanical centrifugal separator with water sprays ^r	0.064	D	ND		ND		0.0037	D	ND	
Sugar cooler (SCC 3-02-016-55)	Mechanical centrifugal separator with water sprays ^r	0.13	D	ND		ND		0.0043	D	ND	
	Venturi scrubber ^s	0.065	D	ND		0.0047	D	0.0042	D	0.0089	D
Sugar conveying and sacking (SCC 3-02-016-61)	Fabric filter	ND		ND		ND		ND		ND	
Sulfur stove (SCC 3-02-016-31)	None	ND		ND		ND		ND		ND	
Pellet Cooler (SCC 3-02-016-16)	None	ND		ND		ND		ND		ND	
Sugar Dryer (SCC 3-02-016-51)	None	ND		ND		ND		ND		ND	

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Table 9.10.1.2-1 (cont.).

		Filterable PM			Condensible PM						
Source	Type of Control	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING	Total	EMISSION FACTOR RATING
Pelletizer (SCC 3-02-016-12)	None	ND		ND		ND		ND		ND	

^a Emission factor units are lb/ton of pressed wet pulp to the dryer, unless noted. Factors represent uncontrolled emissions unless noted. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data.

^b Reference 17.

^c References 7,16-17,19,21.

- ^d References 16-17,19,21.
- ^e References 3,13.
- ^f Reference 13.
- ^g Reference 3.
- ^h References 22-23; both of these facilities utilize gas recirculation systems operating at different rates.
- ^j References 8-12.
- ^k References 11-12.25.
- ^m References 4-6.

ⁿ References 4-6,14. Includes condensible organic PM data from dryers controlled by cyclones and dryers controlled by a dry scrubber and cyclone combination.

- ^p Reference 14.
- ^q References 15,24; fuel gas aspiration systems used at both facilities.
 ^r Reference 20. Emission factor units are lb/ton of sugar output.
- ^s Reference 18. Emission factor units are lb/ton of sugar output.

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Table 9.10.1.2-2.EMISSION FACTORS FOR VOC, METHANE, AND INORGANICPOLLUTANT EMISSIONS FROM SUGARBEET PROCESSING OPERATIONS^a

	lb/ton						
Source	VOC ^b	Methane	NO _x	SO ₂	СО	CO ₂	
Coal-fired pulp dryer ^c (SCC 3-02-016-01)	1.2 ^d	ND	0.66 ^e	0.79 ^f	2.3 ^d	370 ^g	
Natural gas-fired pulp dryer ^c (SCC 3-02-016-08)	ND	ND	ND	ND	ND	156 ^h	
Fuel oil-fired pulp dryer ^c (SCC 3-02-016-05)	0.11 ^j	0.028 ^j	0.60 ^j	1.0 ^k	1.0 ^j	430 ^m	
First evaporator (SCC 3-02-016-41)	ND	ND	ND	ND	ND	ND	
Sulfur stove (SCC 3-02-016-31)	ND	ND	ND	ND	ND	ND	
First carbonation tank (SCC 3-02-016-21)	ND	ND	ND	ND	ND	ND	
Second carbonation tank (SCC 3-02-016-22)	ND	ND	ND	ND	ND	ND	

EMISSION FACTOR RATING: D

^a Emission factor units are lb/ton of pressed wet pulp to the dryer, unless noted. Factors represent uncontrolled emissions unless noted. To convert from lb/ton to kg/Mg, multiply by 0.5.
 SCC = Source Classification Code. ND = no data.

^b Volatile organic compounds as methane.

^c Data for pulp dryers equipped with cyclones, multiclones, wet scrubbers, or a combination of these control technologies are averaged together because these control technologies are not specifically designed to control VOC, methane, NO_x, SO₂, CO, or CO₂ emissions.

- ^d Reference 19.
- ^e References 16,19.
- f References 7,19.
- ^g References 7,13,16-17,19,21. EMISSION FACTOR RATING: B.
- ^h References 8-12,22-23,25. EMISSION FACTOR RATING: C.
- ^j Reference 4.
- k References 14-15.
- ^m References 4-6,14,24. EMISSION FACTOR RATING: C.

Table 9.10.1.2-3. EMISSION FACTORS FOR ORGANIC POLLUTANT EMISSIONS FROM PULP DRYERS^a

		Emission	
Source	CASRN	Name	Factor, lb/ton
Coal-fired pulp dryer with wet	75-07-0	Acetaldehyde	0.015
scrubber	107-02-8	Acrolein	0.0076
(SCC 3-02-016-01)	123-73-9	123-73-9 Crotonaldehyde	
	50-00-0	Formaldehyde	0.0071
	91-57-6	2-methylnaphthalene	1.7x10 ⁻⁵
	88-75-5	2-nitrophenol	0.00018
	95-48-7	2-methylphenol	3.4x10 ⁻⁵
	105-67-9	2,4-dimethylphenol	2.5x10 ⁻⁵
	106-44-5	4-methylphenol	0.00013
	100-02-7	4-nitrophenol	0.00014
	208-96-8	Acenaphthylene	1.7x10 ⁻⁶
	100-52-7	Benzaldehyde	0.0014
	65-85-0	Benzoic acid	0.0028
	100-51-6	Benzyl alcohol	7.1x10 ⁻⁵
	117-81-7	Bis(2-ethylhexyl)phthalate	0.0015
	84-74-2	Di-n-butylphthalate	5.2x10 ⁻⁵
	132-64-9	Dibenzofuran	1.1x10 ⁻⁵
	84-66-2	Diethylphthalate	9.8x10 ⁻⁶
	91-20-3	Naphthalene	0.00011
	98-95-3	Nitrobenzene	1.9x10 ⁻⁵
	85-01-8	Phenanthrene	1.2x10 ⁻⁵
	108-95-2	Phenol	0.00032

EMISSION FACTOR RATING: E

^a Reference 3. Emission factor units are lb/ton of pressed wet pulp to the dryer. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. CASRN = Chemical Abstracts Service Registry Number.

		Pollutant		EMISSION
Source	CASRN	Name	lb/1,000 gal	RATING
First carbonation tank ^b	91-57-6	2-methylnaphthalene	5.1x10 ⁻⁷	D
(SCC 3-02-016-21)	51-28-5	2,4-dinitrophenol ND		D
	106-44-5	4-methylphenol	6.6x10 ⁻⁷	D
	83-32-9	Acenaphthene	ND	D
	100-52-7	Benzaldehyde	1.1x10 ⁻⁴	D
	65-85-0	Benzoic acid	8.4x10 ⁻⁶	D
	100-51-6	Benzyl alcohol	5.0x10 ⁻⁶	D
	117-81-7	Bis(2-ethylhexyl)phthalate	1.2x10 ⁻⁵	D
	91-20-3	Naphthalene	2.0x10 ⁻⁶	D
	85-01-8	Phenanthrene	1.4x10 ⁻⁶	D
	108-95-2	Phenol	1.3x10 ⁻⁶	D
Second carbonation tank ^b	75-07-0	Acetaldehyde	0.0043	Е
(SCC 3-02-016-22)	107-02-8	Acrolein	2.4x10 ⁻⁴	Е
	123-73-9	Crotonaldehyde	3.0x10 ⁻⁵	Е
	50-00-0	Formaldehyde	1.6x10 ⁻⁵	Е
First evaporator ^c	75-07-0	Acetaldehyde	6.7x10 ⁻⁵	Е
(SCC 3-02-016-41)	107-02-8	Acrolein	4.2x10 ⁻⁷	Е
	123-73-9	Crotonaldehyde	1.4x10 ⁻⁷	Е
	50-00-0	Formaldehyde	7.0x10 ⁻⁷	Е
	106-44-5	4-methylphenol	ND	Е
	100-52-7	Benzaldehyde	2.2x10 ⁻⁶	Е
	65-85-0	Benzoic acid	ND	Е
	100-51-6	Benzyl alcohol	1.8x10 ⁻⁷	Е
	117-81-7	Bis(2-ethylhexyl)phthalate	3.7x10 ⁻⁷	Е
	84-74-2	Di-n-butylphthalate	1.1x10 ⁻⁹	Е
	132-64-9	Dibenzofuran	ND	E
	84-66-2	Diethylphthalate	ND	Е
	78-59-1	Isophorone	ND	Е
	91-20-3	Naphthalene	2.5x10 ⁻⁸	Е
	85-01-8	Phenanthrene	1.6x10 ⁻⁸	Е
	108-95-2	Phenol	1.2x10 ⁻⁸	E
	110-86-1	Pyridine	3.4x10 ⁻⁸	E

Table 9.10.1.2-4. EMISSION FACTORS FOR ORGANIC POLLUTANT EMISSIONS FROM CARBONATION TANKS AND EVAPORATORS^a

^a Reference 3. SCC = Source Classification Code. CASRN = Chemical Abstracts Service Registry Number. ND = no data.
 ^b Emission factor units are lb per 1,000 gallons of raw juice produced.
 ^c Emission factor units are lb per 1,000 gallons of thin juice produced.

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9.10.2 Salted And Roasted Nuts And Seeds

This industry encompasses a range of edible nuts and seeds processed primarily for human consumption. The salted and roasted nuts and seeds industry primarily includes establishments that produce salted, roasted, dried, cooked, or canned nuts, or that process grains and seeds for snack use. This industry does not encompass facilities that manufacture candy-coated nuts or those that manufacture peanut butter. The overall production of finished salted and roasted nuts and seeds has two primary components. Typically, nuts undergo post harvest processing such as hulling and shelling, either by the farmer on the farm, or by contractor companies either on the farm or at facilities near the farm, called crop preparation service facilities. The shelled nuts or seeds are shipped to food processing plants to produce the final product.

Many of the post-harvest operations and processes are common to most of the nuts and seeds, including field harvesting and loading, unloading, precleaning, drying, screening, and hulling. Other operations specific to individual nuts and seeds include sizing, grading, skinning, and oil or dry roasting. The processing of harvested nuts and seeds can produce particulate emissions primarily from the unloading, precleaning, hulling or shelling, and screening operations. In almond processing, all of the operations, except for unloading, are usually controlled to reduce the level of ambient particulate. The emissions from the unloading operation are usually uncontrolled.

In this document, the industry is divided into Section 9.10.2.1, "Almond Processing", and Section 9.10.2.2, "Peanut Processing". Sections on other nuts and seeds may be published in later editions if sufficient data on the processes are available.

9.10.2.1 Almond Processing

9.10.2.1.1 General¹⁻²

Almonds are edible tree nuts, grown principally in California. The nuts are harvested from orchards and transported to almond processing facilities, where the almonds are hulled and shelled. The function of an almond huller/sheller is to remove the hull and shell of the almond from the nut, or meat. Orchard debris, soil, and pebbles represent 10 to 25 percent of the field weight of material brought to the almond processing facility. Clean almond meats are obtained as about 20 percent of the field weight. Processes for removing the debris and almond hulls and shells are potential sources of air emissions.

9.10.2.1.2 Process Description¹⁻⁷

After almonds are collected from the field, they undergo two processing phases, post-harvest processing and finish processing. These phases are typically conducted at two different facilities. There are two basic types of almond post-harvest processing facilities: those that produce hulled, inshell almonds as a final product (known as hullers), and those that produce hulled, shelled, almond meats as a final product (known as huller/shellers). Almond precleaning, hulling, and separating operations are common to both types of facilities. The huller/sheller includes additional steps to remove the almond meats from their shells. A typical almond hulling operation is shown in Figure 9.10.2.1-1. A typical almond huller/sheller is depicted in Figure 9.10.2.1-2. The hulled, shelled almond meats are shipped to large production facilities where the almonds may undergo further processing into various end products. Almond harvesting, along with precleaning, hulling, shelling, separating, and final processing operations, is discussed in more detail below.

Almond harvesting and processing are a seasonal industry, typically beginning in August and running from two to four months. However, the beginning and duration of the season vary with the weather and with the size of the crop. The almonds are harvested either manually, by knocking the nuts from the tree limbs with a long pole, or mechanically, by shaking them from the tree. Typically the almonds remain on the ground for 7 to 10 days to dry. The fallen almonds are then swept into rows. Mechanical pickers gather the rows for transport to the almond huller or huller/sheller. Some portion of the material in the gathered rows includes orchard debris, such as leaves, grass, twigs, pebbles, and soil. The fraction of debris is a function of farming practices (tilled versus untilled), field soil characteristics, and age of the orchard, and it can range from less than 5 to 60 percent of the material collected. On average, field weight yields 13 percent debris, 50 percent hulls, 14 percent shells, and 23 percent clean almond meats and pieces, but these ratios can vary substantially from farm to farm.

The almonds are delivered to the processing facility and are dumped into a receiving pit. The almonds are transported by screw conveyors and bucket elevators to a series of vibrating screens. The screens selectively remove orchard debris, including leaves, soil, and pebbles. A destoner removes stones, dirt clods, and other larger debris. A detwigger removes twigs and small sticks. The air streams from the various screens, destoners, and detwiggers are ducted to cyclones or fabric filters for particulate matter removal. The recovered soil and fine debris, such as leaves and grass, are disposed of by spreading on surrounding farmland. The recovered twigs may be chipped and used as fuel for co-generation plants. The precleaned almonds are transferred from the precleaner area by another series of conveyors and elevators to storage bins to await further processing. (In



Figure 9.10.2.1-1. Representative almond hulling process flow diagram. (Source Classification Codes in parentheses.)

9.10.2.1-2

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Figure 9.10.2.1-2. Representative almond huller/sheller process flow diagram. (Source Classification Codes in parentheses.)

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some instances, the precleaned almonds may be conveyed to a dryer before storage. However, field drying is used in most operations.)

Almonds are conveyed on belt and bucket conveyors to a series of hulling cylinders or shear rolls, which crack the almond hulls. Hulling cylinders are typically used in almond huller facilities. Series of shear rolls are generally used in huller/shellers. The hulling cylinders have no integral provision for aspiration of shell pieces. Shear rolls, on the other hand, do have integral aspiration to remove shell fragments from loose hulls and almond meats. The cracked almonds are then discharged to a series of vibrating screens or a gravity table, which separates hulls and unhulled almonds from the in-shell almonds, almond meats, and fine trash. The remaining unhulled almonds pass through additional hulling cylinders or shear rolls and screen separators. The number of passes and the combinations of equipment vary among facilities. The hulls are conveyed to storage and sold as an ingredient in the manufacture of cattle feed. The fine trash is ducted to a cyclone or fabric filter for collection and disposal.

In a hulling facility, the hulled, in-shell almonds are separated from any remaining hull pieces in a series of air legs (counter-flow forced air gravity separators) and are then graded, collected, and sold as finished product, along with an inevitable small percentage of almond meats. In huller/shellers, the in-shell almonds continue through more shear rolls and screen separators.

As the in-shell almonds make additional passes through sets of shear rolls, the almond shells are cracked or sheared away from the meat. More sets of vibrating screens separate the shells from the meats and small shell pieces. The separated shells are aspirated and collected in a fabric filter or cyclone, and then conveyed to storage for sale as fuel for co-generation plants. The almond meats and small shell pieces are conveyed on vibrating conveyor belts and bucket elevators to air classifiers or air legs that separate the small shell pieces from the meats. The number of these air separators varies among facilities. The shell pieces removed by these air classifiers are also collected and stored for sale as fuel for co-generation plants. The revenues generated from the sale of hulls and shells are generally sufficient to offset the costs of operating the almond processing facility.

The almond meats are then conveyed to a series of gravity tables or separators (classifier screen decks), which sort the meats by lights, middlings, goods, and heavies. Lights, middlings, and heavies, which still contain hulls and shells, are returned to various points in the process. Goods are conveyed to the finished meats box for storage. Any remaining shell pieces are aspirated and sent to shell storage.

The almond meats are now ready either for sales as raw product or for further processing, typically at a separate facility. The meats may be blanched, sliced, diced, roasted, salted, or smoked. Small meat pieces may be ground into meal or pastes for bakery products. Almonds are roasted by gradual heating in a rotating drum. They are heated slowly to prevent the skins and outer layers from burning. Roasting time develops the flavor and affects the color of the meats. To obtain almonds with a light brown color and a medium roast requires a 500-pound roaster fueled with natural gas about 1.25 hours at 118°C ($245^{\circ}F$).

9.10.2.1.3 Emissions And Controls^{1-3,5-9}

Particulate matter (PM) is the primary air pollutant emitted from almond post-harvest processing operations. All operations in an almond processing facility involve dust generation from the movement of trash, hulls, shells, and meats. The quantity of PM emissions varies depending on the type of facility, harvest method, trash content, climate, production rate, and the type and number of controls used by the facility. Fugitive PM emissions are attributable primarily to unloading

operations, but some fugitive emissions are generated from precleaning operations and subsequent screening operations.

Because farm products collected during harvest typically contain some residual dirt, which includes trace amounts of metals, it stands to reason that some amount of these metals will be emitted from the various operations along with the dust. California Air Resources Board (CARB) data indicate that metals emitted from almond processing include arsenic, beryllium, cadmium, copper, lead, manganese, mercury, and nickel in quantities on the order of 5×10^{-11} to 5×10^{-4} kilograms (kg) of metal per kg of PM emissions (5×10^{-11} to 5×10^{-4} pounds [lb] of metal per lb of PM emissions). It has been suggested that sources of these metals other than the inherent trace metal content of soil may include fertilizers, other agricultural sprays, and groundwater.

In the final processing operations, almond roasting is a potential source of volatile organic compound (VOC) emissions. However, no chemical characterization data are available to hypothesize what compounds might be emitted, and no emission source test data are available to quantify these potential emissions.

Emission control systems at almond post-harvest processing facilities include both ventilation systems to capture the dust generated during handling and processing of almonds, shells, and hulls, and an air pollution control device to collect the captured PM. Cyclones formerly served as the principal air pollution control devices for PM emissions from almond post harvest processing operations. However, fabric filters, or a combination of fabric filters and cyclones, are becoming common. Practices of combining and controlling specific exhaust streams from various operations vary considerably among facilities. The exhaust stream from a single operation may be split and ducted to two or more control devices. Conversely, exhaust streams from several operations may be combined and ducted to a single control device. According to one source within the almond processing industry, out of approximately 350 almond hullers and huller/shellers, no two are alike.

Emission factors for almond processing sources are presented in Table 9.10.2.1-1.

Table 9.10.2.1-1 (Metric And English Units). EMISSION FACTORS FOR ALMOND PROCESSING^a

	Filterable PM		Condensable Inorganic PM		РМ-10 ^b	
Source	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Unloading ^c (SCC 3-02-017-11)	0.030	0.060	ND	ND	ND	ND
Precleaning cyclone ^d (SCC 3-02-017-12)	0.48	0.95	ND	ND	0.41	0.82
Precleaning baghouse ^e (SCC 3-02-017-12)	0.0084	0.017	ND	ND	0.0075	0.015
Hulling/separating cyclone ^d (SCC 3-02-017-13)	0.57	1.1	ND	ND	0.41	0.81
Hulling/separating baghouse ^e (SCC 3-02-017-13)	0.0078	0.016	ND	ND	0.0065	0.013
Hulling/shelling baghouse ^f (SCC 3-02-017-14)	0.026	0.051	0.0068	0.014	ND	ND
Classifier screen deck cyclone ^d (SCC 3-02-017-15)	0.20	0.40 K	ND	ND	0.16	0.31
Air leg ^d (SCC 3-02-017-16)	0.26	0.51	ND	ND	ND	ND
Roaster ^g (SCC 3-02-017-17)	ND	ND	ND	ND	ND	ND

EMISSION FACTOR RATING: E

^a Process weights used to calculate emission factors include nuts and orchard debris as taken from the field, unless noted. ND = no data. SCC = Source Classification Code.

^b PM-10 factors are based on particle size fractions found in Reference 1 applied to the filterable PM emission factor for that source. See Reference 3 for a detailed discussion of how these emission factors were developed.

^c References 1-3, 10-11.

^d Reference 1. Emission factor is for a single air leg/classifier screen deck cyclone. Facilities may contain multiple cyclones.

^e References 1,9.

^f Reference 10.

^g Factors are based on finished product throughputs.

References For Section 9.10.2.1

- 1. Report On Tests Of Emissions From Almond Hullers In The San Joaquin Valley, File No. C-4-0249, California Air Resources Board, Division Of Implementation And Enforcement, Sacramento, CA, 1974.
- 2. Proposal To Almond Hullers And Processors Association For Pooled Source Test, Eckley Engineering, Fresno, CA, December 1990.
- 3. Emission Factor Documentation For AP-42 Section 9.10.2, Salted And Roasted Nuts And Seeds, EPA Contract No. 68-D2-0159, Midwest Research Institute, Cary, NC, May 1994.
- 4. Jasper Guy Woodroof, Tree Nuts: Production, Processing Product, Avi Publishing, Inc., Westport, CT, 1967.
- 5. Written communication from Darin Lundquist, Central California Almond Growers Association, Sanger, CA, to Dallas Safriet, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 9, 1993.
- 6. Written communication from Jim Ryals, Almond Hullers and Processors Association, Bakersfield, CA, to Dallas Safriet, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 7, 1993.
- 7. Written communication from Wendy Eckley, Eckley Engineering, Fresno, CA, to Dallas Safriet, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 7, 1993.
- 8. Private communications between Wendy Eckley, Eckley Engineering, Fresno, CA, and Lance Henning, Midwest Research Institute, Kansas City, MO, August-September 1992, March 1993.
- 9. Almond Huller Baghouse Emissions Tests, Superior Farms, Truesdail Laboratories, Los Angeles, CA, November 5, 1980.
- 10. Emission Testing On Two Baghouses At Harris Woolf California Almonds, Steiner Environmental, Inc., Bakersfield, CA, October 1991.
- 11. Emission Testing On One Baghouse At Harris Woolf California Almonds, Steiner Environmental, Inc., Bakersfield, CA, October 1992.

9.10.2.2 Peanut Processing

9.10.2.2.1 General

Peanuts (Arachis hypogaea), also known as groundnuts or goobers, are an annual leguminous herb native to South America. The peanut peduncle, or peg (the stalk that holds the flower), elongates after flower fertilization and bends down into the ground, where the peanut seed matures. Peanuts have a growing period of approximately 5 months. Seeding typically occurs mid-April to mid-May, and harvesting during August in the United States.

Light, sandy loam soils are preferred for peanut production. Moderate rainfall of between 51 and 102 centimeters (cm) (20 and 40 inches [in.]) annually is also necessary. The leading peanut producing states are Georgia, Alabama, North Carolina, Texas, Virginia, Florida, and Oklahoma.

9.10.2.2.2 Process Description

The initial step in processing is harvesting, which typically begins with the mowing of mature peanut plants. Then the peanut plants are inverted by specialized machines, peanut inverters, that dig, shake, and place the peanut plants, with the peanut pods on top, into windrows for field curing. After open-air drying, mature peanuts are picked up from the windrow with combines that separate the peanut pods from the plant using various thrashing operations. The peanut plants are deposited back onto the fields and the pods are accumulated in hoppers. Some combines dig and separate the vines and stems from the peanut pods in 1 step, and peanuts harvested by this method are cured in storage. Some small producers still use traditional harvesting methods, plowing the plants from the ground and manually stacking them for field curing.

Harvesting is normally followed by mechanical drying. Moisture in peanuts is usually kept below 12 percent, to prevent aflatoxin molds from growing. This low moisture content is difficult to achieve under field conditions without overdrying vines and stems, which reduces combine efficiency (less foreign material is separated from the pods). On-farm dryers usually consist of either storage trailers with air channels along the floor or storage bins with air vents. Fans blow heated air (approximately 35°C [95°F]) through the air channels and up through the peanuts. Peanuts are dried to moistures of roughly 7 to 10 percent.

Local peanut mills take peanuts from the farm to be further cured (if necessary), cleaned, stored, and processed for various uses (oil production, roasting, peanut butter production, etc.). Major process steps include processing peanuts for in-shell consumption and shelling peanuts for other uses.

9.10.2.2.2.1 In-shell Processing -

Some peanuts are processed for in-shell roasting. Figure 9.10.2.2-1 presents a typical flow diagram for in-shell peanut processing. Processing begins with separating foreign material (primarily soil, vines, stems, and leaves) from the peanut pods using a series of screens and blowers. The pods are then washed in wet, coarse sand that removes stains and discoloration. The sand is then screened from the peanuts for reuse. The nuts are then dried and powdered with talc or kaolin to whiten the shells. Excess talc/kaolin is shaken from the peanut shells.



Figure 9.10.2.2-1. Typical in-shell peanut processing flow diagram.

9.10.2.2.2.2 Shelling -

A typical shelled peanut processing flow diagram is shown in Figure 9.10.2.2-2. Shelling begins with separating the foreign material with a series of screens, blowers, and magnets. The cleaned peanuts are then sized with screens (size graders). Sizing is required so that peanut pods can be crushed without also crushing the peanut kernels.

Next, shells of the sized peanuts are crushed, typically by passing the peanuts between rollers that have been adjusted for peanut size. The gap between rollers must be narrow enough to crack the peanut hulls, but wide enough to prevent damage to the kernels. A horizontal drum, with a perforated and ridged bottom and a rotating beater, is also used to hull peanuts. The rotating beater crushes the peanuts against the bottom ridges, pushing both the shells and peanuts through the perforations. The beater can be adjusted for different sizes of peanuts, to avoid damaging the peanut kernels. Shells are aspirated from the peanut kernels as they fall from the drum. The crushed shells and peanut kernels are then separated with oscillating shaker screens and air separators. The separation process also removes undersized kernels and split kernels.

Following crushing and hull/kernel separation, peanut kernels are sized and graded. Sizing and grading can be done by hand, but most mills use screens to size kernels and electric eye sorters for grading. Electric eye sorters can detect discoloration and can separate peanuts by color grades. The sized and graded peanuts are bagged in 45.4-kg (100-lb) bags for shipment to end users, such as peanut butter plants and nut roasters. Some peanuts are shipped in bulk in rail hopper cars.

9.10.2.2.2.3 Roasting -

Roasting imparts the typical flavor many people associate with peanuts. During roasting, amino acids and carbohydrates react to produce tetrahydrofuran derivatives. Roasting also dries the peanuts further and causes them to turn brown as peanut oil stains the peanut cell walls. Following roasting, peanuts are prepared for packaging or for further processing into candies or peanut butter. Typical peanut roasting processes are shown in Figure 9.10-2.2-3. There are 2 primary methods for roasting peanuts, dry roasting and oil roasting.

Dry Roasting -

Dry roasting is either a batch or continuous process. Batch roasters offer the advantage of adjusting for different moisture contents of peanut lots from storage. Batch roasters are typically natural gas-fired revolving ovens (drum-shaped). The rotation of the oven continuously stirs the peanuts to produce an even roast. Oven temperatures are approximately 430°C (800°F), and peanut temperature is raised to approximately 160°C (320°F) for 40 to 60 min. Actual roasting temperatures and times vary with the condition of the peanut batch and the desired end characteristics.

Continuous dry roasters vary considerably in type. Continuous roasting reduces labor, ensures a steady flow of peanuts for other processes (packaging, candy production, peanut butter production, etc.), and decreases spillage. Continuous roasters may move peanuts through an oven on a conveyor or by gravity feed. In one type of roaster, peanuts are fed by a conveyor into a stream of countercurrent hot air that roasts the peanuts. In this system, the peanuts are agitated to ensure that air passes around the individual kernels to promote an even roast.

Dry roasted peanuts are cooled and blanched. Cooling occurs in cooling boxes or on conveyors where large quantities of air are blown over the peanuts immediately following roasting. Cooling is necessary to stop the roasting process and maintain a uniform quality. Blanching removes the skin of the peanut as well as dust, molds, and other foreign material. There are several blanching methods including dry, water, spin, and air impact.



Figure 9.10.2.2-2. Typical shelled peanut processing flow diagram.



Figure 9.10.2.2-3. Typical shelled peanut roasting processing flow diagram.

ROASTED PEANUT BAGGING OR BULK SHIPPING

ROASTED PEANUT

BAGGING OR BULK SHIPPING

AIR

AIR

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Dry blanching is used primarily in peanut butter production, because it removes the kernel hearts which affect peanut butter flavor. Dry blanching heats the peanuts to approximately138°C (280°F) for 25 minutes to crack and loosen the skins. The heated peanuts are then cooled and passed through either brushes or ribbed rubber belting to rub off the skins. Screening is used to separate the hearts from the cotyledons (peanut halves).

Water blanching passes the peanuts on conveyors through stationary blades that slit the peanut skins. The skins are then loosened with hot water sprayers and removed by passing the peanuts under oscillating canvas-covered pads on knobbed conveyor belts. Water blanching requires drying the peanuts back to a moisture content of 6 to 12 percent.

Spin blanching uses steam to loosen the skins of the peanuts. Steaming is followed by spinning the peanuts on revolving spindles as the peanuts move, single file, down a grooved conveyor. The spinning unwraps the peanut skins.

Air impact blanching uses a horizontal drum (cylinder) in which the peanuts are placed and rotated. The inner surface of the drum has an abrasive surface that aids in the removal of the skins as the drum rotates. Inside the drum are air jets that blow the peanuts counter to the rotation of the drum creating air impact which loosens the skin. The combination of air impacts and the abrasive surface of the drum results in skin removal. Either batch or continuous air impact blanching can be conducted.

Oil Roasting -

Oil roasting is also done on a batch or continuous basis. Before roasting, the peanuts are blanched to remove the skins. Continuous roasters move the peanuts on a conveyor through a long tank of heated oil. In both batch and continuous roasters, oil is heated to temperatures of 138 to 143°C (280 to 290°F), and roasting times vary from 3 to 10 minutes depending on desired characteristics and peanut quality. Oil roaster tanks have heating elements on the sides to prevent charring the peanuts on the bottom. Oil is constantly monitored for quality, and frequent filtration, neutralization, and replacement are necessary to maintain quality. Coconut oil is preferred, but oils such as peanut and cottonseed are frequently used.

Cooling also follows oil roasting, so that a uniform roast can be achieved. Cooling is achieved by blowing large quantities of air over the peanuts either on conveyors or in cooling boxes.

9.10.2.2.3 Emissions And Controls

No information is currently available on emissions or emission control devices for the peanut processing industry. However, the similarities of some of the processes to those in the almond processing industry make it is reasonable to assume that emissions would be comparable. No data are available, however, to make any comparisons about relative quantities of these emissions.

Reference For Section 9.10.2.2

1. Jasper Guy Woodroof, *Peanuts: Production, Processing, Products*, 3rd Edition, Avi Publishing Company, Westport, CT, 1983.

9.11 Fats And Oils

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[Work In Progress]

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9.11.1 Vegetable Oil Processing

9.11.1.1 General¹⁻⁵

The industry group producing fats and oils includes cottonseed oil mills, soybean oil mills, vegetable oil mills (other than corn, cottonseed, and soybean), and other mills. Wet corn mills are the primary producers of corn oil. Approximately 137 vegetable oil plants operate in the United States. Soybean processing, which dominates the industry, produces approximately 80 percent of the volume of vegetable oil and is concentrated in the states of Iowa, Illinois, Missouri, Kansas, Indiana, and Minnesota, but also found across the nation. Likewise, wet corn mills are concentrated in Corn Belt states. Cottonseed oil mills are found in southern states and California.

9.11.1.2 Process Description⁶⁻⁹

The following process description discusses only soybean oil manufacture, because emission factors are available only for that activity. Corn, cottonseed, and peanut oil processing are similar to soybean processing, except for differences in the soybean preparation for oil extraction. The process for soybeans typically consists of five steps: oilseed handling/elevator operations, preparation of soybeans for solvent extraction, solvent extraction and oil desolventizing, flake desolventizing, and oil refining.

Oilseed Handling/Elevator Operations -

Figure 9.11.1-1 is a schematic diagram of a typical soybean handling/elevator operation that precedes the preparation of soybeans for the solvent extraction process.

Soybeans received at the facility by truck or rail are sampled and analyzed for moisture content, foreign matter, and damaged seeds. Then the beans are weighed and conveyed to large concrete silos or metal tanks for storage prior to processing. When the facility is ready to process the soybeans, the beans are removed from the silo or tank and cleaned of foreign materials and loose hulls. Screens typically are used to remove foreign materials such as sticks, stems, pods, tramp metal, sand, and dirt. An aspiration system is used to remove loose hulls from the soybeans; these hulls may be combined later with hulls from the dehulling aspiration step. The beans are passed through dryers to reduce their moisture content to approximately 10 to 11 percent by weight and then are conveyed to process bins for temporary storage and tempering for 1 to 5 days in order to facilitate dehulling.

Preparation Of Soybeans For Solvent Extraction -

Figure 9.11.1-2 is a schematic diagram of the process used to prepare soybeans for the solvent extraction process. The process, which is fairly well standardized, consists of four principal operations: cracking, dehulling/hull removal, conditioning, and flaking.

Soybeans are conveyed from the process bins to the mill by means of belts or mass flow conveyors and bucket elevators. In the mill, the beans may be aspirated again, weighed, cleaned of tramp metal by magnets, and fed into corrugated cracking rolls. The cracking rolls "crack" each bean into four to six particles, which are passed through aspirators to remove the hulls (processed separately after the removal of residual bean chips). These hulls may be combined with the hulls from the grain cleaning step.



Figure 9.11.1-1. Flow diagram of typical soybean handling/elevator operations. (Source Classification Codes in parentheses.)



Figure 9.11.1-2. Flow diagram of the typical process for preparing soybeans for solvent extraction. (Source Classification Codes in parentheses.)

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Next, the cracked beans and bean chips are conveyed to the conditioning area, where they are put either into a rotary steam tubed device or into a stacked cooker and are heated to "condition" them (i. e., make them pliable and keep them hydrated). Conditioning is necessary to permit the flaking of the chips and to prevent their being broken into smaller particles. Finally, the heated, cracked beans are conveyed and fed to smooth, cylindrical rolls that press the particles into smooth "flakes", which vary in thickness from approximately 0.25 to 0.51 millimeters (0.010 to 0.020 inches). Flaking allows the soybean oil cells to be exposed and the oil to be more easily extracted.

Solvent Extraction and Oil Desolventizing -

The extraction process consists of "washing" the oil from the soybean flakes with hexane solvent in a countercurrent extractor. Then the solvent is evaporated (i. e., desolventized) from both the solvent/oil mixture (micella) and the solvent-laden, defatted flakes (see Figure 9.11.1-3). The oil is desolventized by exposing the solvent/oil mixture to steam (contact and noncontact). Then the solvent is condensed, separated from the steam condensate, and reused. Residual hexane not condensed is removed with mineral oil scrubbers. The desolventized oil, called "crude" soybean oil, is stored for further processing or loadout.

Desolventizing Flakes -

The flakes leaving the extractor contain up to 35 to 40 percent solvent and must be desolventized before use. Flakes are desolventized in one of two ways: either "conventional" desolventizing or specialty or "flash" desolventizing. The method used depends upon the end use of the flakes. Flakes that are flash desolventized are typically used for human foods, while conventionally desolventized flakes are used primarily in animal feeds.

Conventional desolventizing takes place in a desolventizer-toaster (DT), where both contact and noncontact steam are used to evaporate the hexane. In addition, the contact steam "toasts" the flakes, making them more usable for animal feeds. The desolventized and toasted flakes then pass to a dryer, where excess moisture is removed by heat, and then to a cooler, where ambient air is used to reduce the temperature of the dried flakes. The desolventized, defatted flakes are then ground for use as soybean meal (see Figure 9.11.1-4).

Flash desolventizing is a special process that accounts for less than 5 percent by volume of the annual nationwide soybean crush. The production of flakes for human consumption generally follows the flow diagram in Figure 9.11.1-3 for the "conventional" process, except for the desolventizing step. In this step, the flakes from the oil extraction step are "flash" desolventized in a vacuum with noncontact steam or superheated hexane. This step is followed by a final solvent stripping step using steam. Both the hexane vapor from the flash/vacuum desolventizer and the hexane and steam vapors from the stripper are directed to a condenser. From the condenser, hexane vapors pass to the mineral oil scrubber and the hexane-water condensate goes to the separator, as shown in Figure 9.11.1-3. The flakes produced by the flash process are termed "white flakes". A process flow diagram for the flash desolventizing portion of the soybean process is shown in Figure 9.11.1-5. From the stripper, the white flakes pass through a cooker (an optional step) and a cooler prior to further processing steps similar to the "conventional" process. A plant that uses specialty or "flash" desolventizing requires different equipment and is far less efficient in energy consumption and solvent recovery than a plant that uses conventional desolventizing. Given these facts, solvent emissions are considerably higher for a specialty desolventizing process.



Soybean Extraction Facility--Total Hexane Losses (3-02-019-97) (3-02-019-98)

Figure 9.11.1-3. Flow diagram of the "conventional" solvent extraction process. (Source Classification Codes in parentheses.)

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Figure 9.11.1-4. Flow diagram for "conventional" process of dry material sizing, grinding, and loadout. (Source Classification Codes in parentheses.)

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Figure 9.11.1-5. Flow diagram of the flash desolventizing process. (Source Classification Code in parentheses.)

Vegetable Oil Refining -

Crude oil is typically shipped for refining to establishments engaged in the production of edible vegetable oils, shortening, and margarine. Crude vegetable oils contain small amounts of naturally occurring materials such as proteinaceous material, free fatty acids, and phosphatides. Phosphatides are removed for lecithin recovery or to prepare the crude oil for export. The most common method of refining oil is by reacting it with an alkali solution which neutralizes the free fatty acids and reacts with the phosphatides. These reacted products and the proteinaceous materials are then removed by centrifuge. Following alkali refining, the oil is washed with water to remove residual soap, caused by saponification of small amounts of the triglycerides (oil). Color-producing substances within an oil (i. e., carotenoids, chlorophyll) are removed by a bleaching process, which employs the use of adsorbents such as acid-activated clays. Volatile components are removed by deodorization, which uses steam injection under a high vacuum and temperature. The refined oil is then filtered and stored until used or transported.

9.11.1.3 Emissions And Controls^{6,10-20}

Emissions -

Particulate matter and volatile organic compounds are the principal emissions from vegetable oil processing. Particulate matter (PM) results from the transfer, handling, and processing of raw seed. VOC emissions are the oil extraction solvent, hexane, which is classified as a hazardous air pollutant. Particulate emissions from grain handling are discussed in the Interim AP-42 Section 9.9.1, "Grain Elevators And Processes".

Solvent emissions arise from several sources within vegetable oil processing plants. There are potential solvent emissions from the transfer and storage of hexane on site as well as potential leaks from piping and vents. Small quantities of solvent (up to 0.2 percent by volume of oil) are present in the crude vegetable oil after the solvent is recovered by film evaporators and the distillation stripper. This hexane may volatilize during the oil-refining process; however, no emission data are available. Trace quantities of solvent are present and available for volatilization in waste water collected from the condensation of steam used in the distillation stripper and desolventizer-toaster. Emission data from waste water also are not available.

Vents are another source of emissions. Solvent is discharged from three vents: the main vent from the solvent recovery section, the vent from the meal dryer, and the vent from the meal cooler. The main vent receives gases from the oil extractor, the film evaporator and distillation stripper, and the desolventizer-toaster. Vents for the meal dryer and meal cooler typically vent to atmosphere.

Hexane Emissions -

The recommended method for estimating annual hexane emissions from soybean solvent extraction facilities is to obtain the annual hexane usage from the specific plant's records, and to assume that all hexane make-up is due to losses to the air (SCC 3-02-019-97). (Some hexane leaves the facilities as a small fraction of the oil or meal products, but this amount has not been quantified.) If the hexane usage is determined from purchase records and the purchased amount accounts for any change in quantities stored on-site, then storage tank losses would already be accounted for in the loss estimate. If the usage is determined from the amount metered out of the storage tanks, then the storage tank losses should be calculated separately, and in addition to, the usage losses, using the equations in AP-42 Chapter 7 or in the TANKS software. Careful application of such a material balance approach should produce emission estimates comparable in quality to those derived from a B-rated emission factor.

The mean total hexane loss reported by the plants in References 11 through 19 was 3.3 L/Mg (0.89 gal/ton [4.9 lb/ton]) of raw soybeans processed (SCC 3-02-019-98). This represents an overall total loss factor for soybean oil processing, encompassing all sources of vented and fugitive emissions (and storage tanks), as well as any hexane leaving the facility as part of the oil or meal products. For a new facility or if plant-specific usage data are unavailable, this factor, rated D, can be used as a default value until the relevant data for the facility become available. The default value should be used only until the facility can compile the data needed to develop a plant-specific hexane loss for the period of interest.

Particulate Emissions -

Table 9.11.1-1 presents emission factors for total PM emissions resulting from handling and processing soybeans in vegetable oil manufacturing. Emission factors are provided for PM-generating processes for the meal production process, including meal drying and cooling.

Table 9.11.1-1. TOTAL PARTICULATE EMISSION FACTORS FOR SOYBEAN MILLING*

Process	Control Device	Emission Factor (lb/ton) ^b
Receiving ^o (SCC 3-02-007-81)	None	0.15
Handling (SCC 3-02-007-82)	ND	ND
Cleaning (SCC 3-02-007-83)	ND	ND
Drying (SCC 3-02-007-84)	ND	ND
Cracking/dehulling (SCC 3-02-007-85)	Cyclone	0.36
Hull grinding (SCC 3-02-007-86)	Cyclone	0.20
Bean conditioning (SCC 3-02-007-87)	Cyclone	0.010
Flaking rolls (SCC 3-02-007-88)	Cyclone	0.037
White flake cooler (SCC 3-02-007-92)	Cyclone	0.95
Meal cooler (SCC 3-02-007-90)	Cyclone	0.19
Meal dryer (SCC 3-02-007-89)	Cyclone	0.18
Meal grinder/sizing (SCC 3-02-007-93)	Cyclone	0.34
Meal loadout ^d (SCC 3-02-007-91)	None	0.27

EMISSION FACTOR RATING: E

- ^a Emission factors are based on pounds per ton of soybeans processed by the unit. Factors represent controlled emissions, except as noted. Divide the lb/ton factor by two to obtain kg/Mg. SCC = Source Classification Code, ND = No Data.
- ^b Reference 21. These data were obtained from unpublished emission test data and from industry questionnaires. Because these are secondary data, the test data and the questionnaire results were weighed equally and the emission factors were calculated as arithmetic means of the data. The emission factor rating is a reflection of the source of the data.
- [°] See Interim AP-42 Section 9.9.1, "Grain Elevators And Processes".

^d Reference 22.

Controls -

Hexane is recovered and reused in the oil-extraction process because of its cost. The steam and hexane exhausts from the solvent extractor, desolventizer-toaster, and oil/hexane stripping are passed through condensers to recover hexane. Residual hexane from the condensers is captured by mineral oil scrubbers. The most efficient recovery or control device is a mineral oil scrubber (MOS), which is approximately 95 percent efficient. The meal dryer and cooler vents are typically exhausted to the atmosphere with only cyclone control to reduce particulate matter. Process controls to reduce breakdowns and leaks can be used effectively to reduce emissions. Quantities of hexane may be lost through storage tanks, leaks, shutdowns, or breakdowns. These losses are included in the material balance. References for Section 9.11.1

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9.12 Beverages

- 9.12.1 Malt Beverages
- 9.12.2 Wines And Brandy
- 9.12.3 Distilled And Blended Liquors

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9.12.1 Malt Beverages

9.12.1.1 Process Description¹⁻⁴

The production of malt beverages, or beer, comprises four main stages: brewhouse operations, fermentation, aging or secondary fermentation, and packaging. Figures 9.12.1-1, 9.12.1-2, 9.12.1-3, and 9.12.1-4 show the various stages of a typical brewing process, including potential emission points.

Breweries typically purchase malted grain (malt) from malting operations. In the malting process, grain is first soaked in water-filled steeping tanks for softening. After softening, the grain is transferred to germination tanks, in which the grain germinates, typically over a 1-week period. From the germination tanks, the grain enters a kiln, which halts germination by drying the grain. To begin the brewing process, malt (usually barley malt) is transported by truck or rail to a brewery and is conveyed to storage silos. The malt is then ground into malt flour by malt mills and transferred to milled malt hoppers. Many small breweries purchase malt flour (malted and milled grain) from facilities with malt mills. Malt provides the starch-splitting and protein-splitting enzymes that are necessary to convert grain starches into fermentable sugars.

From the milled malt hoppers, the malt, along with hot water, is fed to the mash tun and heated to convert grain starches to fermentable sugars. Some large facilities use high-temperature mashing, which reduces the time required to convert the starches to sugars, but lowers the quantity of fermentable sugars produced. Most breweries use one of the three principal mashing processes; these are: double mashing, decoction, and infusion. Double mashing uses grains other than barley (typically corn and rice) as starch adjuncts. Before being added to the mash tun, the adjunct grains are broken down through cooking in a cereal cooker for about 1 hour at temperatures ranging from 40° to 100° C (104° to 212° F). Some plants do not use cereal cookers, but use additives such as corn syrup that function as adjunct grains. The malt and adjuncts are then mixed and heated in the mash tun. Decoction is a method of boiling portions of the mixture (mash) and adding the boiling portions to the mash tun to raise the overall temperature to about 75° C (167° F). The infusion process mixes the malt with hot water to maintain a uniform temperature (65° to 75° C [149° to 167° F]) until starch conversion is complete. Mixing, heating times, and temperatures vary among breweries. The finished product of mashing is a grain slurry, called mash.

From the mash tun, the mash is pumped to a straining tank called a lauter tun, which separates insoluble grain residues from the mash. The mash enters the lauter tun through a false bottom where the insoluble grain residues are allowed to settle. The grain sediment acts as a filter for the mash as it enters the tank. Various other filter agents, such as polypropylene fibers, are also used. Some large breweries use strainmasters, which are a variation of lauter tuns. The spent grain (brewers grain) from the lauter tun or strainmaster is conveyed to holding tanks, dried (by some breweries), and sold as animal feed. Brewers grain dryers are typically fired with natural gas or fuel oil. The product of the lauter tun is called wort.

The strained wort from the lauter tun is transferred to the brew kettle and is boiled, typically for about 90 to 120 minutes. Boiling stops the starch-to-sugar conversion, sterilizes the wort, precipitates hydrolyzed proteins, concentrates the wort by evaporating excess water, and facilitates chemical changes that affect beer flavor. Hops are added to the wort during the boiling process. Hops are high in $iso-\alpha$ acids, which impart the characteristic bitter flavor to beer. Some breweries

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Figure 9.12.1-1. Typical brewery grain handling and malting operations. (Source Classification Codes in parentheses.)



Figure 9.12.1-2. Typical brewhouse operations. (Source Classification Codes in parentheses.)

9.12.1-3



Figure 9.12.1-3. Typical fermentation and post-fermentation brewery operations. (Source Classification Codes in parentheses.)



Figure 9.12.1-4. Typical filling room operations. (Source Classification Codes in parentheses.)

add only hop extracts (that contain the desired iso- α acids), and some breweries add hop extracts during or after the fermentation process. After brewing, the hops are strained from the hot wort, and the hot wort is pumped to a large settling tank, where it is held to allow the remaining insoluble material (trub) to settle. The trub is transferred to the spent grain holding tanks. After settling, the hot wort is pumped to a cooling system (typically a closed system), which cools the liquid to temperatures ranging from about 7° to 12°C (44° to 54°F). Following cooling, yeast is added to the cooled wort as it is pumped to the fermenters.

Fermentation takes place in large tanks (fermenters--typically with capacities $\geq 1,000$ barrels for medium to large breweries) that can be either open or closed to the atmosphere. Most closed-tank fermenters include CO₂ collection systems, which recover CO₂ for internal use and remove organic impurities from the CO₂; water scrubbers and activated carbon adsorption systems are used to recover impurities. These closed tank fermenters typically vent emissions to the atmosphere (for a specified period of time) until the CO₂ is pure enough to collect. The scrubber water is commonly discharged as process wastewater, and the activated carbon is typically recharged (regenerated) on-site (the impurities are typically vented to the atmosphere).

Fermentation is a biological process in which yeast converts sugars into ethyl alcohol (ethanol), carbon dioxide (CO₂), and water. Yeasts can ferment at either the bottom or the top of the fermenter. Saccharomyces carlsbergensis are common bottom-fermenting yeasts used to produce lager beers. Bottom-fermenting yeasts initially rise to the top of the fermenter, but then flocculate to the bottom during rapid fermentation. When fermentation moderates, the beer is run off the top of the fermenter, leaving the bottom-fermenting yeasts at the bottom of the tank. Saccharomyces cerevisiae are top-fermenting yeasts commonly used to produce ales, porters, and stout beers. Top-fermenting yeasts rise to the top of the fermenter during rapid fermentation and are skimmed or centrifuged off the top when fermentation moderates. The type of yeast used and the length of the fermentation process vary among breweries and types of beer. Most pilsner beers ferment at temperatures varying from 6° to $20^{\circ}C$ (43° to $68^{\circ}F$).

After primary fermentation, waste yeast is typically removed from the liquid (by centrifuges or other means), and the liquid proceeds to a secondary fermentation or aging process. The liquid is pumped to aging tanks, a small quantity of freshly fermenting wort is added (at some breweries), and the mixture is stored at low temperatures (below about $5^{\circ}C$ [41°F]).

Several methods are used for the disposal of yeast, including: recovery of viable yeast for reuse in the fermentation process, sale to animal feed processors, distillation to recover residual ethanol, and disposal as process wastewater.

After the beer is aged, solids are typically removed by centrifugation or filtration with diatomaceous earth filters, and the beer is pumped to final storage (beer storage tanks). From final storage, the beer is pumped to the packaging (canning and bottling) facility.

Packaging facilities typically include several canning and bottling lines, as well as a keg filling operation. Most facilities pasteurize beer after canning or bottling, although some facilities package nonpasteurized products using sterile filling lines. Beer that spills during packaging is typically collected by a drainage system, and can be processed to remove or recover ethanol before discharge as process wastewater. Damaged and partially filled cans and bottles are typically collected, crushed, and recycled. Beer from the damaged cans and bottles can be processed to remove or recover ethanol before discharge as industrial sewage. The final steps in the process are labeling, packaging for distribution, and shipping.

Microbreweries typically produce beer for on-site consumption, although some have limited local keg distribution. The beer production process is similar to that of large breweries, although several processes may be excluded or combined. Most microbreweries purchase bags of either malted barley or malt flour for use in beer making. Malt flour requires no processing and is added directly to the mash tun. The facilities that use malted barley typically have a small "cracker" that cracks the grain prior to mashing. Brewhouse operations (mashing, brewers grain settling, brewing, and trub settling) may be combined to decrease the number of tanks required. Fermentation tanks and storage tanks are much smaller than large brewery tanks, with capacities as small as a few barrels. Many microbrews are held in fermentation tanks for three to four weeks (far longer than most mass-produced beers). Canning and bottling operations typically are not found in microbreweries.

9.12.1.2 Emissions And Controls¹⁻⁴

Ethanol is the primary volatile organic compound (VOC) emitted from the production of malt beverages. Aldehydes, ethyl acetate, other VOCs, CO_2 , and particulate matter (PM) are also generated and potentially emitted.

Potential VOC emission sources include mash tuns, cereal cookers, lauter tuns or strainmasters, brew kettles, hot wort settling tanks, yeast storage and propagation (see AP-42 Section 9.13.4), fermenters, spent grain holding tanks, activated charcoal regeneration systems (at breweries with CO_2 recovery), aging tanks (sometimes referred to as "ruh" storage tanks), other storage tanks, and packaging operations. The operations that precede fermentation are sources of various species of VOC. Post-fermentation operations emit primarily ethanol; however, small quantities of ethyl acetate and various aldehydes may also be emitted from fermenters and post-fermentation operations. Other VOC that are emitted from cooking processes (mash tuns, hot wort tanks, and brew kettles) may include dimethyl sulfide, C_5 -aldehydes, and myrcene (a hop oil emitted from brew kettles).

Fermenters are a source of ethanol, other VOC, and CO_2 ; large breweries typically recover CO_2 for internal use. However, smaller breweries and microbreweries typically vent CO_2 to the atmosphere.

Potential sources of PM emissions from breweries include grain malting, grain handling and processing operations (see AP-42 Section 9.9.1), brewhouse operations, and spent-grain drying.

Emissions from microbreweries consist of the same pollutants as large brewery emissions. No test data are available to quantify these emissions, but they are expected to be negligible based on the amount of beer produced in these facilities. Emission control devices are not typically used by microbreweries.

Process loss controls are used to reduce emissions from malt beverage production. Add-on emission controls are used to recover CO_2 in the fermentation process and to control PM emissions from grain handling and brewers grain drying. Large breweries typically use CO_2 recovery systems, which can include water scrubbers or activated carbon beds to remove impurities from the CO_2 . The scrubber water is typically discharged as process wastewater, and organic impurities collected by the activated carbon beds are typically released to the atmosphere.

Water scrubbers could potentially be used to control ethanol emissions. However, scrubber efficiency is based, in part, on the pollutant concentration (200 to 300 parts per million by volume [ppmv] is needed for minimal efficiency), and the ethanol concentrations in fermentation rooms are

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typically very low (about 100 ppmv). Incineration is also an inefficient control measure if pollutant concentrations are low. Recovery of ethanol vapor by carbon adsorption or other methods is another control alternative, although the cost of recovery may be high.

Grain handling and processing operations (unloading, conveying, milling, and storage) are typically controlled by fabric filters. Many smaller breweries purchase malt flour, and do not have milling operations.

Each brewery is unique, and source to source variations can significantly affect emissions. These variations result from differences in the brewing process, the type and age of equipment used, and total production. Brewery emissions are also affected by the unique recipes and time and temperature differences during various stages of production.

Emission factors for malt beverage production operations are shown in Tables 9.12.1-1 and 9.12.1-2.

	Filterable PM							
Source/control	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	PM-2.5	EMISSION FACTOR RATING		
Brew kettle ^b (SCC 3-02-009-07)	0.41	E	ND		ND			
Brewers grain dryer (SCC 3-02-009-30,-32)	26 ^c	D	0.33 ^d	D	0.091 ^d	D		
Brewers grain dryer with wet scrubber (SCC 3-02-009-30,-32)	0.42 ^c	D	0.11 ^d	D	0.060 ^d	D		

Table 9.12.1-1. EMISSION FACTORS FOR MALT BEVERAGES^a

^a Emission factor units are lb of pollutant per 1,000 bbl of beer packaged unless noted.

1 bbl = 31 U.S. gallons. ND = no data available. SCC = Source Classification Code. b Reference 9.

^c References 11,13,17. Emission factor units are lb of pollutant per ton of dried grain produced.

^d Reference 11. Emission factor units are lb of pollutant per ton of dried grain produced.
Table 9.12.1-2. EMISSION FACTORS FOR MALT BEVERAGES^a

EMISSION FACTOR RATING: E

Process	СО	CO ₂	VOCb	Hydrogen Sulfide
Activated carbon regeneration ^c (SCC 3-02-009-39)	ND	ND	0.035	ND
Aging tankfilling ^d (SCC 3-02-009-08)	ND	26	0.57	ND
Bottle crusher ^e (SCC 3-02-009-61)	ND	ND	0.48	ND
Bottle crusher with water sprays ^e (SCC 3-02-009-61)	ND	ND	0.13	ND
Bottle filling line ^f (SCC 3-02-009-53)	ND	ND	17	ND
Bottle soaker and cleaner ^g (SCC 3-02-009-60)	ND	ND	0.20	ND
Brew kettle ^h (SCC 3-02-009-07)	ND	ND	0.64	ND
Brewers grain dryernatural gas-fired (SCC 3-02-009-30)	ND	840 ^j	0.73 ^k	ND
Brewers grain dryersteam-heated (SCC 3-02-009-32)	0.22 ^m	53 ^m	0.73 ^k	ND
Can crusher with pneumatic conveyor ⁿ (SCC 3-02-009-62)	ND	ND	0.088	ND
Can filling line ^f (SCC 3-02-009-51)	ND	ND	14	ND
Cereal cooker ^p (SCC 3-02-009-22)	ND	ND	0.0075	ND
Fermenter venting: closed fermenter ^q (SCC 3-02-009-35)	ND	2,100	2.0	0.015
Hot wort settling tank ^r (SCC 3-02-009-24)	ND	ND	0.075	ND
Keg filling line ^s (SCC 3-02-009-55)	ND	46	0.69	ND
Lauter tun ^p (SCC 3-02-009-23)	ND	ND	0.0055	ND
Mash tun ^p (SCC 3-02-009-21)	ND	ND	0.054	ND
Open wort cooler ^r (SCC 3-02-009-25)	ND	ND	0.022	ND
Sterilized bottle filling line (SCC 3-02-009-54)	ND	4,300 ^t	40 ^u	ND
Sterilized can filling line (SCC 3-02-009-52)	ND	1,900 ^t	35 ^u	ND

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Process	СО	CO ₂	VOC ^b	Hydrogen Sulfide
Trub vesselfilling ^r (SCC 3-02-009-26)	ND	ND	0.25	ND
Waste beer storage tanks (SCC 3-02-009-65)	ND	ND	ND	ND

- a Emission factor units are lb of pollutant per 1,000 bbl of beer packaged unless noted.
- 1 bbl = 31 U.S. gallons. ND = no data available. SCC = Source Classification Code.b Total organic compounds measured using EPA Method 25A, unless noted otherwise. Pre-fermentation factors are presented as VOC as propane; post-fermentation factors are presented as VOC as ethanol because the emissions have been shown to be primarily ethanol.
- c Reference 19. From CO₂ recovery and purification system on a closed fermenter.
- d
- Reference 6. VOC as ethanol. EMISSION FACTOR RATING: D. Reference 15. VOC as ethanol. Emission factor units are lb of pollutant per batch of bottles e crushed. Crusher averages about 34 crushes per day.
- f Reference 20. Emission factor represents ethanol emissions measured using both EPA Method 18 and an FTIR analyzer. Factor is reported as VOC because ethanol is essentially the only VOC emitted from filling operations.
- g Reference 14. Emission factor units are lb of pollutant per 1000 cases of bottles washed. Emission factor represents ethanol emissions measured by GC/FID. Factor is reported as VOC because ethanol is essentially the only VOC emitted from this operation. EMISSION FACTOR RATING: D.
- ^h References 9,19. VOC as propane.
- j Reference 17. Emission factor units are lb of pollutant per ton of dried grain produced. Emission factor includes data from dryers controlled by wet scrubbers, which do not control CO₂ emissions. **EMISSION FACTOR RATING: D**
- k References 11-13. VOC as propane. Emission factor units are lb of pollutant per ton of dried grain produced. Emission factor includes data from dryers controlled by wet scrubbers, which do not control VOC emissions. EMISSION FACTOR RATING: D.
- m Reference 11. Emission factor units are lb of pollutant per ton of dried grain produced. Emission factor includes data from dryers controlled by wet scrubbers, which do not control CO or CO₂ emissions. EMISSION FACTOR RATING: D.
- n Reference 16. VOC as ethanol. Emission factor units are lb of pollutant per gallon of beer recovered. EMISSION FACTOR RATING: D.
- p
- Reference 19. VOC as propane. Reference 10. VOC as ethanol. Emission factors are based on a 24-hour venting period prior to q CO_2 collection.
- r Reference 5. VOC as propane.
- 8 Reference 5. VOC as ethanol. EMISSION FACTOR RATING: D.
- t Reference 5. EMISSION FACTOR RATING: D.
- u References 5,7-8,18. VOC as ethanol. Emission factor includes measurements of VOC as ethanol measured using EPA Method 25A and ethanol measured using both EPA Method 18 and an FTIR analyzer. EMISSION FACTOR RATING: D.

EMISSION FACTORS

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9.12.2 Wines And Brandy

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9.12.2.1 General

Wine is an alcoholic beverage produced by the fermentation of sugars in fruit juices, primarily grape juice. In general, wines are classified into two types based on alcohol content: table wines (7 percent to 14 percent, by volume) and dessert wines (14 percent to 24 percent, by volume). Table wines are further subdivided into still and sparkling categories, depending upon the carbon dioxide (CO₂) content retained in the bottled wine. Still table wines are divided into three groups: red, rosé (blush), and white, based on the color of the wine.

9.12.2.2 Process Description¹⁻⁴

The production of still table wines is discussed in the following paragraphs, followed by more concise discussions of the production of sweet table wines, sparkling wines, dessert wines, and brandy.

Still Table Wines -

The basic steps in vinification (wine production) include harvesting, crushing, pressing, fermentation, clarification, aging, finishing, and bottling. A simplified process diagram outlining the basic steps in the production of still table wines is shown in Figure 9.12.2-1.

Harvesting of grapes is usually conducted during the cooler periods of the day to prevent or retard heat buildup and flavor deterioration in the grape. Most wineries transport the whole grapes but some crush the grapes in the vineyard and transport the crushed fruit to the winery. Stemming and crushing are commonly conducted as soon as possible after harvest. These two steps are currently done separately using a crusher-stemmer, which contains an outer perforated cylinder to allow the grapes to pass through but prevents the passage of stems, leaves, and stalks. Crushing the grapes after stemming is accomplished by any one of many procedures. The three processes generally favored are: (1) pressing grapes against a perforated wall; (2) passing grapes through a set of rollers; or (3) using centrifugal force. Generally, 25 to 100 milligrams (mg) of liquified sulfur dioxide (SO₂) are added per liter of the crushed grape mass to control oxidation, wild yeast contamination, and spoilage bacteria.

Maceration is the breakdown of grape solids following crushing of the grapes. The major share of the breakdown results from the mechanical crushing but a small share results from enzymatic breakdown. In red and rosé wine production, the slurry of juice, skins, seeds, and pulp is termed the "must". In white wine production, the skins, seeds, and pulp are separated from the juice before inoculation with yeast and only the juice is fermented. A fermenting batch of juice is also called "must". Thus, the term "must" can refer to either the mixture of juice, seeds, skins, and pulp for red or rosé wines or only the juice for white wines. Maceration is always involved in the initial phase of red wine fermentation. The juice from the grapes may be extracted from the "must" in a press. Additionally, gravity flow juicers may be used initially to separate the majority of the juice from the crushed grapes and the press used to extract the juice remaining in the mass of pulp, skins, and seeds (pomace). There are many designs of dejuicers but, generally, they consist of a tank fitted with a perforated basket at the exit end. After gravity dejuicing has occurred, the pomace is placed in a press and the remaining juice extracted. There are three major types of presses. The horizonal press is used for either crushed or uncrushed grapes. A pneumatic press can be used for either crushed or

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Figure 9.12.2.-1. Basic steps in still table wine production. (Source Classification Codes in parentheses.) uncrushed grapes as well as for fermented "must". In the continuous screw press, the "must" is pumped into the press and forced in the pressing chamber where perforated walls allow the juice to escape. After pressing, white "must" is typically clarified and/or filtered prior to fermentation to retain the fruity character. The white juice is commonly allowed to settle for up to 12 hours but may be centrifuged to speed the clarification.

Fermentation is the process whereby the sugars (glucose and fructose) present in the "must" undergo reaction by yeast activity to form ethyl alcohol (ethanol) and CO_2 according to the equation:

$$C_6H_{12}O_6 \rightarrow 2 C_2H_5OH + 2 CO_2$$

In the U. S., the sugar content of the juice is commonly measured with a hydrometer in units of degree Brix (°B), which is grams (g) of sugar per 100 grams of liquid. Fermentation may be initiated by the addition of yeast inoculation to the "must". The fermentation process takes place in tanks, barrels, and vats of a wide variety of shapes, sizes, and technical designs. Tanks are different from vats in that tanks are enclosed, whereas vats have open tops. In most of the larger wineries, tanks have almost completely replaced vats. Since the 1950s, the move has been away from the use of wooden tanks, primarily to stainless steel tanks. Lined concrete tanks are also used, and fiberglass tanks are becoming more popular because of their light weight and lower cost.

The fermentation process is an exothermic reaction and requires temperature control of the fermenting "must". Red wines are typically fermented at 25° to 28°C (70° to 82°F) and white wines at 8° to 15°C (46° to 59°F). Almost all of the fermentation is conducted by the batch process and continuous fermentors are rarely used in the U. S. Size of the fermentors is based primarily on the volume of "must" to be fermented. During fermentation of red wines, the CO₂ released by the yeast metabolism becomes entrapped in the pomace (layer of skins and seeds) and causes it to rise to the top of the tank where it forms a cap. The pomace cap is periodically covered with the "must" to increase color removal, aerate the fermenting "must". For white wines, the main technical requirement is efficient temperature control. Temperature is one of the most influential factors affecting the fermentation process. During fermentation of both white and red "must", the CO₂, water vapor, and ethanol are released through a vent in the top of the tank. Malolactic fermentation sometimes follows the primary fermentation and results in a reduction in acidity and increased pH. There are very diverse opinions about this step because the fermentation, to varying degrees, can improve or reduce wine quality.

After fermentation, all wines undergo a period of adjustment (maturation) and clarification prior to bottling. The process of maturation involves the precipitation of particulate and colloidal material from the wine as well as a complex range of physical, chemical, and biological changes that tend to maintain and/or improve the sensory characteristics of the wine. The major adjustments are acidity modification, sweetening, dealcoholization, color adjustment, and blending. Following the fermentation process, a preliminary clarification step is commonly accomplished by decanting the wine from one vessel to another, called racking, in order to separate the sediment (lees) from the wine. Current racking practices range from manually decanting wine from barrel to barrel to highly sophisticated, automated, tank-to-tank transfers. In all cases, separation occurs with minimal agitation to avoid resuspending the particulate matter. The residue from racking may be filtered to recover wine otherwise lost with the lees or may be used "as is" for brandy production.

Stabilization and further clarification steps follow maturation and initial clarification to produce a permanently clear wine with no flavor faults. The steps entail various stabilization

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procedures, additional clarification (fining), and a final filtration prior to bottling. The most common stabilization technique used for many red wines and some white wines is aging the wine for a period of months or years. Vessels used to store and age wine, termed cooperage, are produced in a wide range of sizes, depending on their intended use. White oak has traditionally been used for the barrels to age wine, but currently its usage is reserved primarily for the production of premium white and red wines and some fortified wines. Water and ethanol are lost through the barrel surfaces and a partial vacuum develops in the space created by this loss. Each barrel is periodically opened and topped off with wine to fill the void created by the ethanol and water loss. Cooperage constructed from materials other than wood has many advantages and is less expensive to maintain. Stainless steel is often preferred, but fiberglass and concrete are also used. In addition to aging, other stabilization procedures are used to prevent formation of potassium bitartrate or calcium tartrate crystals, haziness (casse) resulting from protein coalescence, casse resulting from oxidation of tanning present in the wine, and haziness due to metal ions such as iron and copper. Enzyme mixtures are used to remove polysaccharides which can cause filtration problems and haze formation. Most wines contain viable but dormant microorganisms. Racking is used as an initial step in microbial stabilization but longterm stability frequently requires use of sulfur dioxide as the antimicrobial agent. Other methods include pasteurization and filter sterilization. Sulfur dioxide may be added at various stages in wine production to prevent microbial growth and oxidation. Finishing (fining) agents are commonly added to accelerate the precipitation of suspended material in wine. Prior to bottling, a final clarification step is used to remove any remaining suspended material and microbes in the wine. This step involves only physical methods of clarification, generally a filtration procedure.

Glass bottles are the container of choice for premium quality wines and for sparkling wines. Because of disadvantages such as weight and breakage, glass bottles are sometimes being replaced by new containers, such as bag-in-box, for many standard quality, high volume wines. To protect the wine against microbial spoilage, and to limit oxidation, the SO_2 content in the wine is adjusted to a final level of 50 mg/L before filling. Precaution is taken to minimize contact with air during filling and thereby to reduce oxidation. This is done by either flushing the bottle with inert gas before filling or flushing the headspace with inert gas after filling.

Sweet Table Wines -

The most famous of the sweet wines are those made from noble-rotted, *Botrytis*-infected grapes. These wines are produced to a limited extent in the United States. The *Botrytis* mold acts to loosen the grape's skin so moisture loss occurs rapidly and the sugar concentration increases in the grape. The grapes are then selectively picked, followed by pressing, and fermentation. Fermentation is a slow process, however, because of the high sugar content and the use of SO_2 to retard the growth of undesirable molds and microorganisms. Nonbotrytized sweet wines are also produced by drying the grapes. Drying involves allowing the grapes to dehydrate on mats or trays in the shade for weeks or months and then crushing the grapes and fermenting the concentrated juice. Heating, boiling, or freezing is also used to concentrate juice for semisweet wines.

Sparkling Wines -

Most sparkling wines obtain CO_2 supersaturation using a second alcoholic fermentation, typically induced by adding yeast and sugar to dry white wine. There are three principal methods of sparkling wine production: the *methode champagnoise*, the transfer method, and the bulk method. In the *methode champagnoise*, both red and white grapes may be used, but most sparkling wines are white. The grapes are harvested earlier than those used for still table wines and pressed whole without prior stemming or crushing to extract the juice with a minimum of pigment and tannin extraction. This is important for producing white sparkling wines from red-skinned grapes. Primary fermentation is carried out at approximately $15^{\circ}C$ ($59^{\circ}F$) and bentonite and/or casein may be added

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to aid the process and improve clarity. The blending of wines produced from different sites, varieties, and vintages distinguishes the traditional method. Before preparing the blend (*cuvée*), the individual base wines are clarified and stabilized. Aging typically takes place in stainless steel tanks but occasionally takes place in oak cooperage. The secondary fermentation requires inoculation of the *cuvée* wine with a special yeast strain. A concentrated sucrose solution is added to the *cuvée* just prior to the yeast inoculation. The wine is then bottled, capped, and stacked horizontally at a stable temperature, preferably between 10° to 15° C (50° to 59° F), for the second fermentation. After fermentation, the bottles are transferred to a new site for maturation and stored at about 10° C (50° F).

Riddling is the technique used to remove the yeast sediment (lees). The process involves loosening and suspending the cells by manual or mechanical shaking and turning, and positioning the bottle to move the lees toward the neck. Disgorging takes place about 1 or 2 years after bottling. The bottles are cooled and the necks immersed in an ice/CaCl₂ or ice/glycol solution to freeze the sediment. The disgorging machine rapidly removes the cap on the bottle, allowing for ejection of the frozen yeast plug. The mouth of the bottle is quickly covered and the fluid level is adjusted. Small quantities of SO₂ or ascorbic acid may be added to prevent subsequent in-bottle fermentation and limit oxidation. Once the volume adjustment and other additions are complete, the bottles are sealed with special corks, the wire hoods added, and the bottles agitated to disperse the additions. The bottles are then decorated with their capsule and labels and stored for about 3 months to allow the corks to set in the necks. The transfer method is identical to the *methode champagnoise* up to the riddling stage. During aging, the bottles are stored neck down. When the aging process is complete, the bottles are chilled below 0°C (32°F) before discharge into a transfer machine and passage to pressurized receiving tanks. The wine is usually sweetened, sulfited, clarified by filtration, and sterile filtered just before bottling.

In the bulk method, fermentation of the juice for the base wine may proceed until all the sugar is consumed or it may be prematurely terminated to retain sugars for the second fermentation. The yeast is removed by centrifugation and/or filtration. Once the *cuvée* is formulated, the wines are combined with yeast additives and, if necessary, sugar. The second fermentation takes place in stainless steel tanks similar to those used in the transfer process. Removal of the lees takes place at the end of the second fermentation by centrifugation and/or filtration. The sugar and SO₂ contents are adjusted just before sterile filtration and bottling.

Other methods of production of sparkling wine include the "rural" method and carbonation. The rural method involves prematurely terminating the primary fermentation prior to a second inbottle fermentation. The injection of CO_2 (carbonation) under pressure at low temperatures is the least expensive and the least prestigious method of producing sparkling wines.

Dessert Wines -

Dessert wines are classified together because of their elevated alcohol content. The most common dessert wines are sherries and ports.

Baking is the most popular technique for producing sherries in the United States. Grapes are crushed and stemmed and SO_2 added as soon as possible to control bacteria and oxidation. The maximum amount of juice is separated from the skins and the juice is transferred to fermentors. The juice is inoculated with starter and fermented at temperatures of 25° to 30°C (77° to 86°F). The new wine is then pumped from the fermentor or settling tank to the fortification tank. High proof spirits are added to the sherry material, or shermat, to raise the alcohol content to 17 to 18 percent by volume and then the wine is thoroughly mixed, clarified, and filtered before baking. Slow baking occurs when the wine is stored in barrels exposed to the sun. More rapid baking is achieved through

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the use of artificially heated storage rooms or heating coils in barrels or tanks. After baking, the sherry is cooled, clarified, and filtered. Maturation is then required and is usually carried out in oak barrels. Aging can last from 6 months to 3 years or more.

Port wines are produced by the premature termination of fermentation by addition of brandy. When the fermenting must is separated from the pomace by gravity, it is fortified with wine spirits containing about 77 percent alcohol, by volume. Most white ports are fortified when half the original sugar content has been fermented, except for semidry and dry white ports which are fortified later. The type and duration of aging depend on the desired style of wine. Blending is used to achieve the desired properties of the wine. The final blend is left to mature in oak cooperage for several months prior to fining, filtration, stabilization, and bottling.

Brandy Production —

Brandy is an alcoholic distillate or mixture of distillates obtained from the fermented juice, mash, or wine from grapes or other fruit (e. g., apples, apricots, peaches, blackberries, or boysenberries). Brandy is produced at less than 190° proof and bottled at a minimum of 80° proof. (In the United States, "proof" denotes the ethyl alcohol content of a liquid at 15.6°C (60°F), stated as twice the percent ethyl alcohol by volume.) Two types of spirits are produced from wine or wine residue: beverage brandy and "wine spirits".

In brandy production, the grapes are pressed immediately after crushing. There are major differences in the fermentation process between wine and brandy production. Pure yeast cultures are not used in the fermentation process for brandy. Brandy can be made solely from the fermentation of fruit or can be distilled either from the lees leftover from the racking process in still wine production or from the pomace cap that is leftover from still red wine fermentations.

In the United States, distillation is commenced immediately after the fermentation step, generally using continuous column distillation, usually with an aldehyde section, instead of pot stills. For a detailed discussion of the distillation and aging of distilled spirits, which include brandy and brandy spirits, refer to AP-42 Section 9.12.3, "Distilled And Blended Liquors". After distillation, the brandy is aged in oak casks for 3 to 15 years or more. During aging, some of the ethanol and water seep through the oak and evaporate, so brandy is added periodically to compensate for this loss. Caramel coloring is added to give the brandy a characteristic dark brown color. After aging, the brandy may be blended and/or flavored, and then chilled, filtered, and bottled.

9.12.2.3 Emissions And Controls⁵⁻¹¹

Ethanol and carbon dioxide are the primary compounds emitted during the fermentation step in the production of wines and brandy. Acetaldehyde, methyl alcohol (methanol), n-propyl alcohol, n-butyl alcohol, sec-butyl alcohol, isobutyl alcohol, isoamyl alcohol, and hydrogen sulfide also are emitted but in much smaller quantities compared to ethanol emissions. In addition, a large number of other compounds are formed during the fermentation and aging process. Selected examples of other types of compounds formed and potentially emitted during the fermentation process include a variety of acetates, monoterpenes, higher alcohols, higher acids, aldehydes and ketones, and organosulfides. During the fermentation step, large quantities of CO_2 are also formed and emitted.

Fugitive ethanol emissions also occur during the screening of the red wine, pressing of the pomace cap, aging in oak cooperage, and the bottling process. In addition, as a preservative, small amounts of liquified SO_2 are often added to the grapes after harvest, to the "must" prior to

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fermentation, or to the wine after the fermentation is completed; SO_2 emissions can occur during these steps. There is little potential for VOC emissions before the fermentation step in wine production.

Except for harvesting the grapes and possibly unloading the grapes at the winery, there is essentially no potential for particulate (PM) emissions from this industry.

Emission controls are not currently used during the production of wines or brandy. Five potential control systems have been considered and three have been the subject of pilot-scale emission test studies at wineries or universities in California. The five systems are (1) carbon adsorption, (2) water scrubbers, (3) catalytic incineration, (4) condensation, and (5) temperature control. All of the systems have disadvantages in either low control efficiency, cost effectiveness, or overall applicability to the wide variety of wineries.

Emission factors for VOC and hydrogen sulfide emissions from the fermentation step in wine production are shown in Table 9.12.2-1. The emission factors for controlled ethanol emissions and the uncontrolled emissions of hydrogen sulfide and other VOCs from the fermentation step should be used with caution because the factors are based on a small number of tests and fermentation conditions vary considerably from one winery to another

The only emission factors for wine production processes other than fermentation, were obtained from a 1982 test.⁷ These factors represent uncontrolled fugitive ethanol emissions during handling processes. The factor for fugitive emissions from the pomace screening for red wine (SCC 3-02-011-11) is 0.5 lb/1,000 gal of juice. An ethanol emission factor for the pomace press is applicable only to red wine because the juice for white wine goes through the pomace press before the fermentation step. The emission factor for red wine (SCC 3-02-011-12) is 0.02 lb/ton of pomace. Although fugitive emissions occur during the bottling of both red and white wines, an emission factor is available only for the bottling of white wine. The factor for white wine bottling (SCC 3-02-011-21) is 0.1 lb/1,000 gal of wine. All of these factors are rated E. These emission factors should be used with extreme caution because they are based on a limited number of tests conducted at one winery. There is no emission factor for fugitive emissions from the finishing and stabilization step (aging).

There are no available data that can be used to estimate emission factors for the production of sweet table wines, dessert wines, sparkling wines, or brandy.

Table 9.12.2-1. EMISSION FACTORS FOR WINE FERMENTATION[®]

EMISSION FACTOR RATING: E

Wine type	Type of control	Ethyl alcohol, lb/10 ³ gal	Methyl alcohol, lb/10 ³ gal	n-Propyl alcohol, lb/10 ³ gal	n-Butyl alcohol, lb/10 ³ gal	Sec-Butyl alcohol, lb/10 ³ gal	lsobutyl alcohol, lb/10 ³ gal	Isoamyl alcohol, lb/10 ³ gal	Acet- aldehyde, lb/10 ³ gal	Hydrogen sulfide, lb/10 ³ gal
Red	None ^b	4.6°	0.0025	0.0034	5.5E-5	4.5E-5	0.0036	0.014	0.0027	0.0017
(SCC 3-02-011-06)	Carbon adsorption ^d	0.17°	ND	ND	ND	ND	ND	ND	ND	ND
	Catalytic incineration ^e	1.1	ND	ND	ND	ND	ND	ND	ND	ND
v	Wet scrubber ^e	0.056	ND	ND	ND	ND	ND	ND	ND	ND
White	None ^b	1. 8 °	6.4E-4	0.0023	ND	ND	6.9E-4	0.0051	7.2E-5	0.0014
(SCC 3-02-011-05)	Carbon adsorption ^d	0.092°	ND	ND	ND	ND	ND	ND	ND	ND
	Catalytic incineration ^e	0.15	ND	ND	ND	ND	ND	ND	ND	ND
	Wet scrubber ^e	0.083	ND	ND	ND	ND	ND	ND	ND	ND

^a Emission factor units are lb/1,000 gal of fermented juice produced. SCC = Source Classification Code. ND = no data. ^b References 8-11.

° EMISSION FACTOR RATING: C

^d References 8-10.

° Reference 8.

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- 9. D.F. Todd, et al., "Ethanol Emissions Control From Wine Fermentation Tanks Using Charcoal Adsorption: A Pilot Study", California Air Resources Board, published by California Agricultural Technology Institute, March 1990.
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9.12.3 Distilled And Blended Liquors

[Work In Progress]

9.12.3 Distilled Spirits

9.12.3.1 General¹⁻²

The distilled spirits industry includes the production of whisky, gin, vodka, rum, and brandy. The production of brandy is discussed in AP-42 Section 9.12.2, "Wines and Brandy". Distilled spirits production also may include the production of secondary products such as distillers dried grains used for livestock feed and other feed/food components.

Distilled spirits, including grain spirits and neutral spirits, are produced throughout the United States.¹ The Bureau of Alcohol, Tobacco, and Firearms (BATF) has established "standards of identity" for distilled spirits products.²

9.12.3.2 Process Description³⁻⁴

Distilled spirits can be produced by a variety of processes. Typically, in whisky production, grains are mashed and fermented to produce an alcohol/water solution, that is distilled to concentrate the alcohol. For whiskies, the distilled product is aged to provide flavor, color, and aroma. This discussion will be limited to the production of Bourbon whisky. Figure 9.12.3-1 is a simple diagram of a typical whisky production process. Emission data are available only for the fermentation and aging steps of whisky production.

9.12.3.2.1 Grain Handling And Preparation -

Distilleries utilize premium cereal grains, such as hybrid corn, rye, barley, and wheat, to produce the various types of whisky and other distilled spirits. Grain is received at a distillery from a grainhandling facility and is prepared for fermentation by milling or by malting (soaking the grains to induce germination). All U.S. distillers purchase malted grain instead of performing the malting process onsite.

9.12.3.2.2 Grain Mashing -

Mashing consists of cooking the grain to solubilize the starch from the kernels and to convert the soluble starch to grain sugars with barley malt and/or enzymes. Small quantities of malted barley are sometimes added prior to grain cooking. The mash then passes through a noncontact cooler to cool the converted mash prior to entering the fermenter.

9.12.3.2.3 Fermentation -

The converted mash enters the fermenter and is inoculated with yeast. The fermentation process, which usually lasts 3 to 5 days for whisky, uses yeast to convert the grain sugars into ethanol and carbon dioxide. Congeners are flavor compounds which are produced during fermentation as well as during the barrel aging process. The final fermented grain alcohol mixture, called "beer", is transferred to a "beer well" for holding. From the beer well, the beer passes through a preheater, where it is warmed by the alcohol vapors leaving the still, and then to the distillation unit. The beer still vapors condensed in the preheater generally are returned to the beer still as reflux.



^a Processes require heat. Emissions generated (e.g., CO, CO₂, NO_X, SO₂, PM, and VOCs) will depend on the source of fuel.
 ^b Other compounds can be generated in trace quantities during fermentation including ethyl acetate, fusel oil, furfural, acetaldehyde, sulfur dioxide, and hydrogen sulfide. Acetaldehyde is a hazardous air pollutant (HAP).

Figure 9.12.3-1. Whisky production process. (Source Classification Codes in parentheses).

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9.12.3.2.4 Distillation -

The distillation process separates and concentrates the alcohol from the fermented grain mash. Whisky stills are usually made of copper, especially in the rectifying section, although stainless steel may be used in some stills. Following distillation, the distilled alcohol spirits are pumped to stainless steel tanks and diluted with demineralized water to the desired alcohol concentration prior to filling into oak barrels and aging. Tennessee whisky utilizes a different process from Bourbon in that the distillate is passed through sugar maple charcoal in mellowing vats prior to dilution with demineralized water.

9.12.3.2.5 Grain And Liquid Stillage ("Dryer House Operations") -

In most distilleries, after the removal of alcohol, still bottoms (called whole stillage), are pumped from the distillation column to a dryer house. Whole stillage may be sold, land applied (with permitting), sold as liquid feed, or processed and dried to produce distillers dried grains (DDG) and other secondary products. Solids in the whole stillage are separated using centrifuges or screens; the liquid portion (thin stillage) may be used as a backset or concentrated by vacuum evaporation. The concentrated liquid may be recombined with the solids or dried. Drying is typically accomplished using either steam-heated or flash dryers.

9.12.3.2.6 Warehousing/Aging -

Aging practices differ from distiller to distiller, and even for the same distiller. Variations in the aging process are integral to producing the characteristic taste of a particular brand of distilled spirit. The aging process, which typically ranges from 4 to 8 years or more, consists of storing the new whisky distillate in oak barrels to encourage chemical reactions and extractions between the whisky and the wood. The constituents of the barrel produce the whisky's characteristic color and distinctive flavor and aroma. White oak is used because it is one of the few woods that holds liquids while allowing breathing (gas exchange) through the wood. Federal law requires all Bourbon whisky to be aged in charred new white oak barrels.

The oak barrels and the barrel environment are key to producing distilled spirits of desired quality. The new whisky distillate undergoes many types of physical and chemical changes during the aging process that removes the harshness of the new distillate. As whisky ages, it extracts and reacts with constituents in the wood of the barrel, producing certain trace substances, called congeners, which give whisky its distinctive color, taste, and aroma.

Barrel environment is extremely critical in whisky aging and varies considerably by distillery, warehouse, and even location in the warehouse. Ambient atmospheric conditions, such as seasonal and diurnal variations in temperature and humidity, have a great affect on the aging process, causing changes in the equilibrium rate of extraction, rate of transfer by diffusion, and rate of reaction. As a result, distillers may expose the barrels to atmospheric conditions during certain months, promoting maturation through the selective opening of windows and doors and by other means.

Distillers often utilize various warehouse designs, including single- or multistory buildings constructed of metal, wood, brick, or masonry. Warehouses generally rely upon natural ambient temperature and humidity changes to drive the aging process. In a few warehouses, temperature is adjusted during the winter. However, whisky warehouses do not have the capability to control humidity, which varies with natural climate conditions.

9.12.3.2.7 Blending/Bottling -

Once the whisky has completed its desired aging period, it is transferred from the barrels into tanks and reduced in proof to the desired final alcohol concentration by adding demineralized water.

Following a filtration process that renders it free of any solids, the whisky is pumped to a tank in the bottling house, bottled, and readied for shipment to the distributors.

9.12.3.3 Emissions And Controls³⁻⁶

9.12.3.3.1 Emissions -

The principal emissions from whisky production are volatile organic compounds (VOCs), principally ethanol, and occur primarily during the aging/warehousing stage. In addition to ethanol, other volatile compounds, including acetaldehyde (a HAP), ethyl acetate, glycerol, fusel oil, and furfural, may be produced in trace amounts during aging. A comparatively small source of ethanol emissions may result from the fermentation stage. Smaller quantities of ethyl acetate, isobutyl alcohol, and isoamyl alcohol are generated as well; carbon dioxide is also produced during fermentation. Particulate matter (PM) emissions are generated by the grain receiving, handling, drying, and cleaning processes and are discussed in more detail in AP-42 Section 9.9.1, Grain Elevators and Processes. Other emissions, including SO₂, CO₂, CO, NO_x, and PM may be generated by fuel combustion from power production facilities located at most distilled spirits plant.

Ethanol and water vapor emissions result from the breathing phenomenon of the oak barrels during the aging process. This phenomenon of wood acting as a semipermeable membrane is complex and not well understood. The emissions from evaporation from the barrel during aging are not constant. During the first 6 to 18 months, the evaporation rate from a new barrel is low because the wood must become saturated (known as "soakage") before evaporation occurs. After saturation, the evaporation rate is greatest, but then decreases as evaporation lowers the liquid level in the barrel. The lower liquid level decreases the surface area of the liquid in contact with the wood and thus reduces the surface area subject to evaporation. The rate of extraction of wood constituents, transfer, and reaction depend upon ambient conditions, such as temperature and humidity, and the concentrations of the various whisky constituents. Higher temperature changes cause convection currents in the liquid. The rate of diffusion will depend upon the differences in concentrations of constituents in the wood, liquid, and air blanketing the barrel. The rates of reaction will increase or decrease with the concentration of constituents. The equilibrium concentrations of the various whisky components depend upon the humidity and air flow around the barrel.

Minor emissions are generated when the whisky is drained from the barrels for blending and bottling. Residual whisky remains in the used barrels both as a surface film ("heel") and within the wood ("soakage"). For economic reasons, many distillers attempt to recover as much residual whisky as possible by methods such as rinsing the barrel with water and vacuuming. Generally, barrels are refilled and reentered into the aging process for other distilled spirits at the particular distiller or sealed with a closure (bung) and shipped offsite for reuse with other distilled spirits. Emissions may also be generated during blending and bottle filling, but no data are available.

9.12.3.3.2 Controls -

With the exception of devices for controlling PM emissions, there are very few emission controls at distilleries. Grain handling and processing emissions are controlled through the use of cyclones, baghouses, and other PM control devices (see AP-42 Section 9.9.1). There are currently no current control technologies for VOC emissions from fermenters because the significant amount of grain solids that would be carried out of the fermenters by air entrainment could quickly render systems, such as carbon adsorption, inoperable. Add-on air pollution control devices for whisky aging warehouses are not used because of potential adverse impact on product quality. Distillers ensure that barrel construction is of high quality to minimize leakage, thus reducing ethanol emissions. Ethanol recovery would require the use

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of a collection system to capture gaseous emissions in the warehouse and to process the gases through a recovery system prior to venting them to the atmosphere.

9.12.3.3.3 Emission Factors -

Table 9.12.3-1 provides uncontrolled emission factors for emissions of VOCs from fermentation vats and for emissions of ethanol from aging due to evaporation. Because ethanol is the principal VOC emission from aging, the ethanol emissions factors are reasonable estimates of VOC emissions for these processes. Emission factors for grain receiving, handling, and cleaning may be found in AP-42 Section 9.9.1, Grain Elevators and Processes. Emission factors are unavailable for grain mashing, distillation, blending/bottling, and spent grain drying. An emission factor for carbon dioxide from fermentation vats is also unavailable, although carbon dioxide and ethanol are theoretically generated in equal molecular quantities during the fermentation process.

Table 9.12.3-1. EMISSION FACTORS FOR DISTILLED SPIRITS^a

Source ^b	Ethanol	Ethyl acetate	Isoamyl Alcohol	Isobutyl . Alcohol
Grain mashing (SCC 3-02-010-13)	NA	NA	NA	NA
Fermentation vats (SCC 3-02-010-14)	14.2 ^c	0.046 ^c	0.013 ^c	0.004 ^c
Distillation (SCC 3-02-010-15)	ND	ND	ND	ND
Aging (SCC 3-02-010-17)				
- Evaporation loss ^d	6.9 ^e	ND	ND	ND
Blending/bottling (SCC 3-02-010-18)	ND	ND	ND	ND
Dryer house operations (SCC 3-02-010-02)	ND	ND	ND	ND

EMISSION FACTOR RATING: E

^a Factors represent uncontrolled emissions. SCC = Source Classification Code. ND = no data available. To convert from lb to kg, divide by 2.2. NA = not applicable.

- ^b Emission factors for grain receiving, handling, and cleaning processes are available in AP-42 Section 9.9.1, Grain Elevators and Processes.
- ^c Reference 5 (paper). In units of pounds per 1,000 bushels of grain input.
- ^d Evaporation losses during whisky aging do not include losses due to soakage.
- ^e References 6-7. In units of lb/bbl/yr; barrels have a capacity of approximately 53 gallons.

Recognizing that aging practices may differ from distiller to distiller, and even for different products of the same distiller, a method may be used to estimate total ethanol emissions from barrels during aging. An ethanol emission factor for aging (total loss emission factor) can be calculated based on annual emissions per barrel in proof gallons (PG). The term "proof gallon" refers to a U.S. gallon of proof spirits, or the alcoholic equivalent thereof, containing 50 percent of ethyl alcohol (ethanol) by volume. This calculation method is derived from the gauging of product and measures the difference in the amount of product when the barrel was filled and when the barrel was emptied. Fugitive evaporative

emissions, however, are not the sole difference between these two amounts. During the aging period, product soaks into the barrel, test samples are drawn, and other losses (e. g., spillage, leakage) may occur. Estimates of ethanol loss due to evaporation during aging based only on the gauging of product will produce an overestimate unless soakage and sampling losses (very small losses) are subtracted. The emission factor for evaporation loss in Table 9.12.3-1 represents an overestimate because only data for soakage losses could be calculated; data for other losses were not available.

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9.13 Miscellaneous Food And Kindred Products

- 9.13.1 Fish Processing
- 9.13.2 Coffee Roasting
- 9.13.3 Snack Chip Deep Fat Frying
- 9.13.4 Yeast Production

9.13.1 Fish Processing

9.13.1.1 General

Fish canning and byproduct manufacturing are conducted in 136 plants in 12 states. The majority of these plants are in Washington, Alaska, Maine, Louisiana, and California. Some processing occurs in Delaware, Florida, Illinois, Maryland, New York, and Virginia. The industry experienced an 18 percent increase in the quantity of fish processed in 1990, and additional increases were expected in 1992 as well. Exports of canned fish and fish meal also are increasing because of diminishing supply in other countries.

9.13.1.2 Process Description

Fish processing includes both the canning of fish for human consumption and the production of fish byproducts such as meal and oil. Either a precooking method or a raw pack method can be used in canning. In the precooking method, the raw fish are cleaned and cooked before the canning step. In the raw pack method, the raw fish are cleaned and placed in cans before cooking. The precooking method is used typically for larger fish such as tuna, while the raw pack method is used for smaller fish such as sardines.

The byproduct manufacture segment of the fish industry uses canning or filleting wastes and fish that are not suitable for human consumption to produce fish meal and fish oil.

Canning -

The precooking method of canning (Figure 9.13.1-1) begins with thawing the fish, if necessary. The fish are eviscerated and washed, then cooked. Cooking is accomplished using steam, oil, hot air, or smoke for 1.5 to 10 hours, depending on fish size. Precooking removes the fish oils and coagulates the protein in the fish to loosen the meat. The fish are then cooled, which may take several hours. Refrigeration may be used to reduce the cooling time. After cooling, the head, fins, bones, and undesirable meat are removed, and the remainder is cut or chopped to be put in cans. Oil, brine, and/or water are added to the cans, which are sealed and pressure cooked before shipment.

The raw pack method of canning (Figure 9.13.1-2) also begins with thawing and weighing the fish. They are then washed and possibly brined, or "nobbed", which is removing the heads, viscera, and tails. The fish are placed in cans and then cooked, drained, and dried. After drying, liquid, which may be oil, brine, water, sauce, or other liquids, is added to the cans. Finally, the cans are sealed, washed, and sterilized with steam or hot water.

Byproduct Manufacture -

The only process used in the U. S. to extract oil from the fish is the wet steam process. Fish byproduct manufacturing (Figure 9.13.1-3) begins with cooking the fish at 100°C (lower for some species) in a continuous cooker. This process coagulates the protein and ruptures the cell walls to release the water and oil. The mixture may be strained with an auger in a perforated casing before pressing with a screw press. As the fish are moved along the screw press, the pressure is increased and the volume is decreased. The liquid from the mixture, known as pressing liquor, is squeezed out through a perforated casing.



Figure 9.13.1-1. Flow diagram of precooking method. (Source Classification Codes in parentheses.)



Figure 9.13.1-2. Flow diagram of raw packing method. (Source Classification Codes in parentheses.)



(3) Slightly less odor than direct fired dryers, and no smoke

Figure 9.13.1-3. Flow diagram of fish meal and crude fish oil processing. (Source Classification Codes in parentheses.)

The pressing liquor, which consists of water, oil, and some solids, is transported to a centrifuge or desludger where the solids are removed. These solids are later returned to the press cake in the drying step. The oil and water are separated using a disc-type centrifuge in the oil separator. The oil is "polished" by using hot water washes and centrifugation and is then sent to an oil-refining operation. The water removed from the oil (stickwater) goes to an evaporator to concentrate the solids.

The press cake, stickwater, and solids are mixed and sent to either a direct-fired or an indirect-fired dryer (steam tube dryer). A direct-fired dryer consists of a slowly rotating cylinder through which air, heated to about 600°C by an open flame, passes through the meal to evaporate the liquid. An indirect-fired dryer consists of a fixed cylinder with rotating scrapers that heat the meal with steam or hot fluids flowing through discs, tubes, coils, or the dryer casing itself. Air also passes through this apparatus, but it is not heated and flows in the opposite direction to the meal to entrain the evaporated water. Indirect-fired dryers require twice as much time to dry the meal as direct-fired dryers.

The dried meal is cooled, ground to a size that passes through a U. S. No. 7 standard screen, and transferred by pneumatic conveyor to storage. The ground meal is stored in bulk or in paper, burlap, or woven plastic bags. This meal is used in animal and pet feed because of its high protein content.

The "polished oil" is further purified by a process called "hardening" (Figure 9.13.1-4). First, the polished oil is refined by mixing the oil with an alkaline solution in a large stirred vat. The alkaline solution reacts with the free fatty acids in the oil to form insoluble soaps. The mixture is allowed to settle overnight, and the cleared oil is extracted off the top. The oil is then washed with hot water to remove any remaining soaps.



Figure 9.13.1-4. Oil hardening process.

Bleaching occurs in the next step by mixing the oil with natural clays to remove oil pigments and colored matter. This process proceeds at temperatures between 80 and 116°C, in either a batch or continuous mode. After bleaching, hydrogenation of the unsaturated fatty acid chains is the next step. A nickel catalyst, at a concentration of 0.05 to 0.1 percent by weight, is added to a vat of oil, the mixture is heated and stirred, and hydrogen is injected into the mixture to react with the unsaturated fatty acid chains. After the hydrogenation is completed, the oil is cooled and filtered to remove the nickel.

The hydrogenated oil is refined again before the deodorization step, which removes odor and flavor-producing chemicals. Deodorization occurs in a vacuum chamber where dry, oxygen-free steam is bubbled through the oil to remove the undesirable chemicals. Volatilization of the undesirable chemicals occurs at temperatures between 170 to 230°C. The oil is then cooled to about 38°C before exposure to air to prevent formation of undesirable chemicals.

9.13.1.2 Emissions And Controls

Although smoke and particulate may be a problem, odors are the most objectionable emissions from fish processing plants. The fish byproducts segment results in more of these odorous contaminants than canning, because the fish are often in a further state of decomposition, which usually results in greater concentrations of odors.

The largest odor source in the fish byproducts segment is the fish meal driers. Usually, direct-fired driers emit more odors than steam-tube driers. Direct-fired driers also emit smoke and particulate.

Odorous gases from reduction cookers consist primarily of hydrogen sulfide (H_2S) and trimethylamine $[(CH_3)_3N]$ but are emitted from this stage in appreciably smaller volumes than from fish meal driers. There are virtually no particulate emissions from reduction cookers.

Some odors are produced by the canning processes. Generally, the precooked method emits fewer odorous gases than the raw pack method. In the precooked process, the odorous exhaust gases are trapped in the cookers, whereas in the raw pack process, the steam and odorous gases typically are vented directly to the atmosphere.

Fish cannery and fish byproduct processing odors can be controlled with afterburners, chlorinator-scrubbers, or condensers. Afterburners are most effective, providing virtually 100 percent odor control, but they are costly from a fuel-use standpoint. Chlorinator scrubbers have been found to be 95 to 99 percent effective in controlling odors from cookers and driers. Condensers are the least effective control device.

Particulate emissions from the fish meal process are usually limited to the dryers, primarily the direct-fired dryers, and to the grinding and conveying of the dried fish meal. Because there is a relatively small quantity of fines in the ground fish meal, particulate emissions from the grinding, pneumatic conveyors and bagging operations are expected to be very low. Generally, cyclones have been found to be an effective means to collect particulate from the dryers, grinders and conveyors, and from the bagging of the ground fish meal.

Emission factors for fish processing are presented in Table 9.13.1-1. Factors are expressed in units of kilograms per megagram (kg/Mg) and pounds per ton (lb/ton).

EMISSION FACTORS

Table 9.13.1-1 (Metric And English Units). UNCONTROLLED EMISSION FACTORS FOR FISH CANNING AND BYPRODUCT MANUFACTURE^a

	Particulate		Trimethylamine [(CH ₃) ₃ N]		Hydrogen Sulfide (H ₂ S)	
Process	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Cookers, canning (SCC 3-02-012-04)	Neg	Neg	c	c	c	°
Cookers, scrap						
Fresh fish (SCC 3-02-012-01)	Neg	Neg	0.15 ^c	0.3 ^c	0.005°	0.01 ^c
Stale fish (SCC 3-02-012-02)	Neg	Neg	1.75°	3.5°	0.10 ^c	0.2 ^c
Steam tube dryer (SCC 3-02-012-05)	2.5	5	b	_b	b	b
Direct-fired dryer (SCC 3-02-012-06)	4	8	b	b	_b	b

EMISSION FACTOR RATING: C

^a Reference 1. Factors are in terms of raw fish processed. SCC = Source Classification Code. Neg = negligible.

^b Emissions suspected, but data are not available for quantification.

^c Reference 2.

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9.13.2 Coffee Roasting

9.13.2.1 General

The coffee roasting industry involves the processing of green coffee beans into roasted coffee products, including whole and ground beans and soluble coffee products. The Standard Industrial Classification (SIC) code for coffee roasting is 2095.

9.13.2.2 Process Description¹⁻⁶

The coffee roasting process consists essentially of cleaning, roasting, cooling, grinding, and packaging operations. Figure 9.13.2-1 shows a process flow diagram for a typical coffee roasting operation. Bags of green coffee beans are hand- or machine-opened, dumped into a hopper, and screened to remove debris. The green beans are then weighed and transferred by belt or pneumatic conveyor to storage hoppers. From the storage hoppers, the green beans are conveyed to the roaster. Roasters typically operate at temperatures between 370° and 540°C (698° and 1004°F), and the beans are roasted for a period of time ranging from a few minutes to about 30 minutes. Roasters are typically horizontal rotating drums that tumble the green coffee beans in a current of hot combustion gases; the roasters operate in either batch or continuous modes and can be indirect- or direct-fired. Indirect-fired roasters are roasters in which the burner flame does not contact the coffee beans, although the combustion gases from the burner do contact the beans. Direct-fired roasters contact the beans with the burner flame and the combustion gases. At the end of the roasting cycle, water sprays are used to "quench" the beans. Following roasting, the beans are cooled and run through a "destoner". Destoners are air classifiers that remove stones, metal fragments, and other waste not removed during initial screening from the beans. The destoners pneumatically convey the beans to a hopper, where the beans are stabilize and dry (small amounts of water from quenching exist on the surface of the beans). This stabilization process is called equilibration. Following equilibration, the roasted beans are ground, usually by multi-stage grinders. Some roasted beans are packaged and shipped as whole beans. Finally, the ground coffee is vacuum sealed and shipped.

Additional operations associated with processing green coffee beans include decaffeination and instant (soluble) coffee production. Decaffeination is the process of extracting caffeine from green coffee beans prior to roasting. The most common decaffeination process used in the United States is supercritical carbon dioxide (CO₂) extraction. In this process, moistened green coffee beans are contacted with large quantities of supercritical CO₂ (CO₂ maintained at a pressure of about 4,000 pounds per square inch and temperatures between 90° and 100°C [194° and 212°F]), which removes about 97 percent of the caffeine from the beans. The caffeine is then recovered from the CO₂, typically using an activated carbon adsorption system. Another commonly used method is solvent extraction, typically using oil (extracted from roasted coffee) or ethyl acetate as a solvent. In this process, solvent is added to moistened green coffee beans to extract most of the caffeine from the beans. After the beans are removed from the solvent, they are steam-stripped to remove any residual solvent. The caffeine is then recovered from the solvent, and the solvent is re-used. Water extraction is also used for decaffeination, but little information on this process is available. Decaffeinated coffee beans have a residual caffeine content of about 0.1 percent on a dry basis. Not all facilities have decaffeination operations, and decaffeinated green coffee beans are purchased by many facilities that produce decaffeinated coffee.

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Figure 9.13.2-1. Typical coffee roasting operation. (Source Classification Codes in parentheses.)

EMISSION FACTORS

In the manufacture of instant coffee, extraction follows the roasting and grinding operations. The soluble solids and volatile compounds that provide aroma and flavor are extracted from the coffee beans using water. Water heated to about 175°C (347°F) under pressurized conditions (to maintain the water as liquid) is used to extract all of the necessary solubles from the coffee beans. Manufacturers use both batch and continuous extractors. Following extraction, evaporation or freeze-concentration is used to increase the solubles concentration of the extract. The concentrated extracts are then dried in either spray dryers or freeze dryers. Information on the spray drying and freeze drying processes is not available.

9.13.2.3 Emissions And Controls

Particulate matter (PM), volatile organic compounds (VOC), organic acids, and combustion products are the principal emissions from coffee processing. Several operations are sources of PM emissions, including the cleaning and destoning equipment, roaster, cooler, and instant coffee drying equipment. The roaster is the main source of gaseous pollutants, including alcohols, aldehydes, organic acids, and nitrogen and sulfur compounds. Because roasters are typically natural gas-fired, carbon monoxide (CO) and carbon dioxide (CO₂) emissions are expected as a result of fuel combustion. Decaffeination and instant coffee extraction and drying operations may also be sources of small amounts of VOC. Emissions from the grinding and packaging operations typically are not vented to the atmosphere.

Particulate matter emissions from the receiving, storage, cleaning, roasting, cooling, and stoning operations are typically ducted to cyclones before being emitted to the atmosphere. Gaseous emissions from roasting operations are typically ducted to a thermal oxidizer or thermal catalytic oxidizer following PM removal by a cyclone. Some facilities use the burners that heat the roaster as thermal oxidizers. However, separate thermal oxidizers are more efficient because the desired operating temperature is typically between 650°C and 816°C (1200°F and 1500°F), which is 93°C to 260°C (200°F to 500°F) more than the maximum temperature of most roasters. Some facilities use thermal catalytic oxidizers, which require lower operating temperatures to achieve control efficiencies that are equivalent to standard thermal oxidizers. Catalysts are also used to improve the control efficiency of systems in which the roaster exhaust is ducted to the burners that heat the roaster. Emissions from spray dryers are typically controlled by a cyclone followed by a wet scrubber.

Table 9.13.2-1 presents emission factors for filterable PM and condensible PM emissions from coffee roasting operations. Table 9.13.2-2 presents emission factors for volatile organic compounds (VOC), methane, CO, and CO₂ emissions from roasting operations. Emissions from batch and continuous roasters are shown separately, but with the exception of CO emissions, the emissions from these two types of roasters appear to be similar.

Table 9.13.2-1. EMISSION FACTORS FOR COFFEE ROASTING OPERATIONS^a

Source	Filterable PM, lb/ton	Condensible PM lb/ton
Batch roaster with thermal oxidizer ^b (SCC 3-02-002-20)	0.12	ND
Continuous cooler with cyclone [°] (SCC 3-02-002-28)	0.028	ND
Continuous roaster ^d (SCC 3-02-002-21)	0.66	ND
Continuous roaster with thermal oxidizer (SCC 3-02-002-21)	0.092°	0.10°
Green coffee bean screening, handling, and storage system with fabric filter ^f (SCC 3-02-002-08)	0.059	ND
Destoner (SCC 3-02-002-30)	ND	ND
Equilibration (SCC 3-02-002-34)	ND	ND

EMISSION FACTOR RATING: D

^a Emission factors are based on green coffee bean feed. Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data. D-rated and E-rated emission factors are based on limited test data; these factors may not be representative of the industry.

- ^b References 12,14.
- ° Reference 15.
- ^d References 8-9.
- [°] References 7-9,11,15. Includes data from thermal catalytic oxidizers.
- ^f Reference 16. EMISSION FACTOR RATING: E.

Table 9.13.2-2. EMISSION FACTORS FOR COFFEE ROASTING OPERATIONS^a

Source	VOC ^b , lb/ton	Methane, lb/ton	CO, lb/ton	CO ₂ , lb/ton
Batch roaster ^c (SCC 3-02-002-20)	0.86	ND	ND	180
Batch roaster with thermal oxidizer (SCC 3-02-002-20)	0.047 ^d	ND	0.55 ^d	530°
Continuous roaster (SCC 3-02-002-21)	1.4 ^f	0.26 ^g	1.5 ^h	120'
Continuous roaster with thermal oxidizer (SCC 3-02-002-21)	0.16 ^k	0.15 [™]	0.098 ^k	200ª
Decaffeination: solvent or supercritical CO_2 extraction (SCC 3-02-002-10,-11)	ND	ND	ND	ND
Steam or hot air dryer (SCC 3-02-002-16)	ND	ND	ND	ND
Spray drying (SCC 3-02-003-01)	ND	ND	ND	ND
Freeze drying (SCC 3-02-003-06)	ND	ND	ND	ND

EMISSION FACTOR RATING: D

^a Emission factors are based on green coffee bean feed. Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data. D-rated and E-rated emission factors are based on limited test data; these factors may not be representative of the industry.

- ^b Volatile organic compounds as methane. Measured using GC/FID.
- ° Reference 14.
- ^d References 12-14.
- ^e References 12,14.
- ^f References 8-9,11,15.
- ^g References 8-9,11,15. EMISSION FACTOR RATING: E.
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- ^j References 8-9,11,15. EMISSION FACTOR RATING: C.
- ^k References 8-9,11,15. Includes data from thermal catalytic oxidizers.
- ^m References 8-9,11,15. Includes data from thermal catalytic oxidizers. EMISSION FACTOR RATING: E.
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9.13.3 Snack Chip Deep Fat Frying

9.13.3.1 General¹⁻³

The production of potato chips, tortilla chips, and other related snack foods is a growing, competitive industry. Sales of such snack chips in the United States are projected to grow 5.7 percent between 1991 and 1995. Between 1987 and 1991, potato chip sales increased from 649×10^6 kilograms (kg) to 712 x 10^6 kg (1,430 x 10^6 pounds [lb] to 1,570 x 10^6 lb), an increase of 63×10^6 kg (140 x 10^6 lb) (10 percent). Snack chip plants are widely dispersed across the country, with the highest concentrations in California and Texas.

New products and processes are being developed to create a more health-conscious image for snack chips. Examples include the recent introduction of multigrain chips and the use of vegetable oils (noncholesterol) in frying. Health concerns are also encouraging the promotion and introduction of nonfried snack products like pretzels, popcorn, and crackers.

9.13.3.2 Process Description¹

Vegetables and other raw foods are cooked by industrial deep fat frying and are packaged for later use by consumers. The batch frying process consists of immersing the food in the cooking oil until it is cooked and then removing it from the oil. When the raw food is immersed in hot cooking oil, the oil replaces the naturally occurring moisture in the food as it cooks. Batch and continuous processes may be used for deep fat frying. In the continuous frying method, the food is moved through the cooking oil on a conveyor. Potato chips are one example of a food prepared by deep fat frying. Other examples include corn chips, tortilla corn chips, and multigrain chips.

Figure 9.13.3-1 provides general diagrams for the deep fat frying process for potato chips and other snack chips. The differences between the potato chip process and other snack chip processing operations are also shown. Some snack food processes (e. g., tortilla chips) include a toasting step. Because the potato chip processes represent the largest industry segment, they are discussed here as a representative example.

In the initial potato preparation, dirt, decayed potatoes, and other debris are first removed in cleaning hoppers. The potatoes go next to washers, then to abrasion, steam, or lye peelers. Abrasion is the most popular method. Preparation is either batch or continuous, depending on the number of potatoes to be peeled.

The next step is slicing, which is performed by a rotary slicer. Potato slice widths will vary with the condition of the potatoes and with the type of chips being made. The potato slices move through rotating reels where high-pressure water separates the slices and removes starch from the cut surfaces. The slices are then transferred to the rinse tank for final rinsing.

Next, the surface moisture is removed by 1 or more of the following methods: perforated revolving drum, sponge rubber-covered squeeze roller, compressed air systems, vibrating mesh belt, heated air, or centrifugal extraction.

The partially dried chips are then fried. Most producers use a continuous process, in which the slices are automatically moved through the fryer on a mesh belt. Batch frying, which is used for


Figure 9.13.3-1. Generalized deep fat frying process for snack foods. (Source Classification Codes in parentheses.)

a smaller quantity of chips, involves placing the chips in a frying kettle for a period of time and then removing them. A variety of oils may be used for frying chips, with cottonseed, corn, and peanut oils being the most popular. Canola and soybean oils also are used. Animal fats are rarely used in this industry.

As indicated in Figure 9.13.3-1, the process for other snack chips is similar to that for potato chip frying. Typically, the raw material is extruded and cut before entering the fryer. In some cases, the chips may be toasted before frying.

9.13.3.2 Emissions And Controls²⁻³

Emissions -

Particulate matter is the major air pollutant emitted from the deep fat frying process. Emissions are released when moist foodstuff, such as potatoes, is introduced into hot oil. The rapid vaporization of the moisture in the foodstuff results in violent bubbling, and cooking oil droplets, and possibly vapors, become entrained in the water vapor stream. The emissions are exhausted from the cooking vat and into the ventilation system. Where emission controls are employed, condensed water and oil droplets in the exhaust stream are collected by control devices before the exhaust is routed to the atmosphere. The amount of particulate matter emitted depends on process throughput, oil temperature, moisture content of the feed material, equipment design, and stack emission controls.

Volatile organic compounds (VOC) are also produced in deep fat frying, but they are not a significant percentage of total frying emissions because of the low vapor pressure of the vegetable oils used. However, when the oil is entrained into the water vapor produced during frying, the oil may break down into volatile products. Small amounts of VOC and combustion products may also be emitted from toasters, but quantities are expected to be negligible.

Tables 9.13.3-1 and 9.13.3-2 provide uncontrolled and controlled particulate matter emission factors, in metric and English units, for snack chip frying. Table 9.13.3-3 provides VOC emission factors, in metric and English units, for snack chip frying without controls. Emission factors are calculated as the weight of particulate matter or VOC per ton of finished product, including salt and seasonings.

Controls -

Particulate matter emission control equipment is typically installed on potato chip fryer exhaust streams because of the elevated particulate loadings caused by the high volume of water contained in potatoes. Examples of control devices are mist eliminators, impingement devices, and wet scrubbers. One manufacturer has indicated that catalytic and thermal incinerators are not practical because of the high moisture content of the exhaust stream.

Table 9.13.3-1 (Metric Units). PARTICULATE MATTER EMISSION FACTORS FOR SNACK CHIP DEEP FAT FRYING^a

	Filtera	able PM	Condensable PM			Total
Process	PM	PM-10	Inorganic	Organic	Total	PM-10
Continuous deep fat fryer-potato chips ^b (SCC 3-02-036-01)	0.83	ND	ND	ND	0.19	ND
Continuous deep fat fryerother snack chips ^b (SCC 3-02-036-02)	0.28	ND	ND	ND	0.12	ND
Continuous deep fat fryer with standard mesh pad mist eliminator potato chips ^c (SCC 3-02-036-01)	0.35 ^d	0.30	0.0040 ^d	0.19 ^d	0.19	0.49
Continuous deep fat fryer with high-efficiency mesh pad mist eliminator-potato chips ^e (SCC 3-02-036-01)	0.12	ND	0.12	0.064	0.18	ND
Continuous deep fat fryer with standard mesh pad mist eliminator other snack chips ^f (SCC 3-02-036-02)	0.11 ^d	0.088	0.017	0.022	0.039	0.13
Batch deep fat fryer with hood scrubberpotato chips ^g (SCC 3-02-036-03)	0.89 ^d	ND	0.66 ^d	0.17	0.83	ND

EMISSION FACTOR RATING: E (except as noted)

^a Factors are for uncontrolled emissions, except as noted. All emission factors in kg/Mg of chips produced. SCC = Source Classification Code. ND = no data.

^b Reference 3.

^c References 6, 10-11. The standard mesh pad mist eliminator, upon which these emission factors are based, includes a single, 6-inch, 2-layer mist pad that operates with a pressure drop of about 0.5-inch water column (when clean).

d EMISSION FACTOR RATING: D

^e References 4-5. The high-efficiency mesh pad eliminator, upon which these emission factors are based, includes a coarse-weave 4-inch mist pad and a 6-inch fine weave pad, and operates with a 2.5- to 3-inch water column pressure drop (when clean).

^f References 6-7.

^g References 8-9.

Table 9.13.3-2 (English Units). PARTICULATE MATTER EMISSION FACTORS FOR SNACK CHIP DEEP FAT FRYING^a

	Filtera	able PM	Condensable PM			Total
Process	РМ	PM-10	Inorganic	Organic	Total	PM-10
Continuous deep fat fryerpotato chips ^b (SCC 3-02-036-01)	1.6	ND	ND	ND	0.39	ND
Continuous deep fat fryerother snack chips ^b (SCC 3-02-036-02)	0.56	ND	ND	ND	0.24	ND
Continuous deep fat fryer with standard mesh pad mist eliminatorpotato chips ^c (SCC 3-02-036-01)	0.70 ^d	0.60	0.0080 ^d	0.37 ^d	0.38	0.98
Continuous deep fat fryer with high- efficiency mesh pad mist eliminatorpotato chips ^e (SCC 3-02-036-01)	0.24	ND	0.23	0.13	0.36	ND
Continuous deep fat fryer with standard mesh pad mist eliminatorother snack chips ^f (SCC 3-02-036-02)	0.22 ^d	0.18	0.034	0.044	0.078	0.26
Batch deep fat fryer with hood scrubberpotato chips ^g (SCC 3-02-036-03)	1.8 ^d	ND	1.3 ^d	0.33	1.6	ND

EMISSION FACTOR RATING: E (except as noted)

^a Factors are for uncontrolled emissions, except as noted. All emission factors in lb/ton of chips produced. SCC = Source Classification Code. ND = no data.

^b Reference 3.

^c References 6, 10-11. The standard mesh pad mist eliminator, upon which these emission factors are based, includes a single, 6-inch, 2-layer mist pad that operates with a pressure drop of about 0.5 inch water column (when clean).

^d EMISSION FACTOR RATING: D

^e References 4-5. The high-efficiency mesh pad eliminator, upon which these emission factors are based, includes a coarse-weave 4-inch mist pad and a 6-inch fine weave pad and operates with a 2.5- to 3-inch water column pressure drop (when clean).

f References 6-7.

^g References 8-9.

Table 9.13.3-3 (Metric Units). UNCONTROLLED VOC EMISSION FACTORS FOR SNACK CHIP DEEP FAT FRYING^{a,b}

EMISSION FACTOR RATING: E

	VOC			
Process	kg/Mg	lb/ton		
Deep fat fryer—potato chips (SCC 3-02-036-01)	0.0099	0.020		
Deep fat fryer—other snack chips (SCC 3-02-036-02)	0.043	0.085		

^a Reference 3. SCC = Source Classification Code.

^b Expressed as equivalent weight of methane (CH_{4}) /unit weight of product.

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9.13.4 Yeast Production

9.13.4.1 General¹

Baker's yeast is currently manufactured in the United States at 13 plants owned by 6 major companies. Two main types of baker's yeast are produced, compressed (cream) yeast and dry yeast. The total U. S. production of baker's yeast in 1989 was 223,500 megagrams (Mg) (245,000 tons). Of the total production, approximately 85 percent of the yeast is compressed (cream) yeast, and the remaining 15 percent is dry yeast. Compressed yeast is sold mainly to wholesale bakeries, and dry yeast is sold mainly to consumers for home baking needs. Compressed and dry yeasts are produced in a similar manner, but dry yeasts are developed from a different yeast strain and are dried after processing. Two types of dry yeast are produced, active dry yeast (ADY) and instant dry yeast (IDY). Instant dry yeast is produced from a faster-reacting yeast strain than that used for ADY. The main difference between ADY and IDY is that ADY has to be dissolved in warm water before usage, but IDY does not.

9.13.4.2 Process Description¹

Figure 9.13.4-1 is a process flow diagram for the production of baker's yeast. The first stage of yeast production consists of growing the yeast from the pure yeast culture in a series of fermentation vessels. The yeast is recovered from the final fermentor by using centrifugal action to concentrate the yeast solids. The yeast solids are subsequently filtered by a filter press or a rotary vacuum filter to concentrate the yeast further. Next, the yeast filter cake is blended in mixers with small amounts of water, emulsifiers, and cutting oils. After this, the mixed press cake is extruded and cut. The yeast cakes are then either wrapped for shipment or dried to form dry yeast.

Raw Materials¹⁻³ -

The principal raw materials used in producing baker's yeast are the pure yeast culture and molasses. The yeast strain used in producing compressed yeast is *Saccharomyces cerevisiae*. Other yeast strains are required to produce each of the 2 dry yeast products, ADY and IDY. Cane molasses and beet molasses are the principal carbon sources to promote yeast growth. Molasses contains 45 to 55 weight percent fermentable sugars, in the forms of sucrose, glucose, and fructose.

The amount and type of cane and beet molasses used depend on the availability of the molasses types, costs, and the presence of inhibitors and toxins. Usually, a blend consisting of both cane and beet molasses is used in the fermentations. Once the molasses mixture is blended, the pH is adjusted to between 4.5 and 5.0 because an alkaline mixture promotes bacteria growth. Bacteria growth occurs under the same conditions as yeast growth, making pH monitoring very important. The molasses mixture is clarified to remove any sludge and is then sterilized with high-pressure steam. After sterilization, it is diluted with water and held in holding tanks until it is needed for the fermentation process.

A variety of essential nutrients and vitamins is also required in yeast production. The nutrient and mineral requirements include nitrogen, potassium, phosphate, magnesium, and calcium, with traces of iron, zinc, copper, manganese, and molybdenum. Normally, nitrogen is supplied by adding ammonium salts, aqueous ammonia, or anhydrous ammonia to the feedstock. Phosphates and magnesium are added, in the form of phosphoric acid or phosphate salts and magnesium salts. Vitamins are also required for yeast growth (biotin, inositol, pantothenic acid, and thiamine).



Figure 9.13.4-1. Typical process flow diagram for the seven-stage production of baker's yeast, with Source Classification Codes shown for compressed yeast. Use 3-02-035-XX for compressed yeast.

Thiamine is added to the feedstock. Most other vitamins and nutrients are already present in sufficient amounts in the molasses malt.

Fermentation¹⁻³ -

Yeast cells are grown in a series of fermentation vessels. Yeast fermentation vessels are operated under aerobic conditions (free oxygen or excess air present) because under anaerobic conditions (limited or no oxygen) the fermentable sugars are consumed in the formation of ethanol and carbon dioxide, which results in low yeast yields.

The initial stage of yeast growth takes place in the laboratory. A portion of the pure yeast culture is mixed with molasses malt in a sterilized flask, and the yeast is allowed to grow for 2 to 4 days. The entire contents of this flask are used to inoculate the first fermentor in the pure culture stage. Pure culture fermentations are batch fermentations, where the yeast is allowed to grow for 13 to 24 hours. Typically, 1 to 2 fermentors are used in this stage of the process. The pure culture fermentations are basically a continuation of the flask fermentation, except that they have provisions for sterile aeration and aseptic transfer to the next stage.

Following the pure culture fermentations, the yeast mixture is transferred to an intermediate fermentor that is either batch or fed-batch. The next fermentation stage is a stock fermentation. The contents from the intermediate fermentor are pumped into the stock fermentor, which is equipped for incremental feeding with good aeration. This stage is called stock fermentor liquid by centrifuging, which produces a stock, or pitch, of yeast for the next stage. The next stage, pitch fermentation, also produces a stock, or pitch, of yeast. Aeration is vigorous, and molasses and other nutrients are fed incrementally. The liquor from this fermentor is usually divided into several parts for pitching the final trade fermentations (adding the yeast to start fermentation). Alternately, the yeast may be separated by centrifuging and stored for several days before its use in the final trade fermentations.

The final trade fermentation has the highest degree of aeration, and molasses and other nutrients are fed incrementally. Large air supplies are required during the final trade fermentations, so these vessels are often started in a staggered fashion to reduce the size of the air compressors. The duration of the final fermentation stages ranges from 11 to 15 hours. After all of the required molasses has been fed into the fermentor, the liquid is aerated for an additional 0.5 to 1.5 hours to permit further maturing of the yeast, making it more stable for refrigerated storage.

The amount of yeast growth in the main fermentation stages described above increases with each stage. Yeast growth is typically 120 kilograms (270 pounds) in the intermediate fermentor, 420 kilograms (930 pounds) in the stock fermentor, 2,500 kilograms (5,500 pounds) in the pitch fermentor, and 15,000 to 100,000 kilograms (33,000 to 220,000 pounds) in the trade fermentor.

The sequence of the main fermentation stages varies among manufacturers. About half of existing yeast operations are 2-stage processes, and the remaining are 4-stage processes. When the 2-stage final fermentation series is used, the only fermentations following the pure culture stage are the stock and trade fermentations. When the 4-stage fermentation series is used, the pure culture stage is followed by intermediate, stock, pitch, and trade fermentations.

Harvesting And Packaging¹⁻² -

Once an optimum quantity of yeast has been grown, the yeast cells are recovered from the final trade fermentor by centrifugal yeast separators. The centrifuged yeast solids are further concentrated by a filter press or rotary vacuum filter. A filter press forms a filter cake containing 27 to 32 percent solids. A rotary vacuum filter forms cakes containing approximately 33 percent solids. This filter cake is then blended in mixers with small amounts of water, emulsifiers, and cutting oils to form the end product. The final packaging steps, as described below, vary depending on the type of yeast product.

In compressed yeast production (SCC 3-02-035-XX), emulsifiers are added to give the yeast a white, crearny appearance and to inhibit water spotting of the yeast cakes. A small amount of oil, usually soybean or cottonseed oil, is added to help extrude the yeast through nozzles to form continuous ribbons of yeast cake. The ribbons are cut, and the yeast cakes are wrapped and cooled to below $8^{\circ}C$ (46°F), at which time they are ready for shipment in refrigerated trucks.

In dry yeast production (SCC 3-02-034-XX), the product is sent to an extruder after filtration, where emulsifiers and oils (different from those used for compressed yeast) are added to texturize the yeast and to aid in extruding it. After the yeast is extruded in thin ribbons, it is cut and dried in either a batch or a continuous drying system. Following drying, the yeast is vacuum packed or packed under nitrogen gas before heat sealing. The shelf life of ADY and IDY at ambient temperature is 1 to 2 years.

9.13.4.3 Emissions^{1,4-5}

Volatile organic compound (VOC) emissions are generated as byproducts of the fermentation process. The 2 major VOCs emitted are ethanol and acetaldehyde. Other byproducts consist of other alcohols, such as butanol, isopropyl alcohol, 2,3-butanediol, organic acids, and acetates. Based on emission test data, approximately 80 to 90 percent of total VOC emissions is ethanol, and the remaining 10 to 20 percent consists of other alcohols and acetaldehyde. Acetaldehyde is a hazardous air pollutant as defined under Section 112 of the *Clean Air Act*.

Volatile byproducts form as a result of either excess sugar (molasses) present in the fermentor or an insufficient oxygen supply to it. Under these conditions, anaerobic fermentation occurs, breaking down the excess sugar into alcohols and carbon dioxide. When anaerobic fermentation occurs, 2 moles of ethanol and 2 moles of carbon dioxide are formed from 1 mole of glucose. Under anaerobic conditions, the ethanol yield is increased, and yeast yields are decreased. Therefore, in producing baker's yeast, it is essential to suppress ethanol formation in the final fermentation stages by incremental feeding of the molasses mixture with sufficient oxygen to the fermentor.

The rate of ethanol formation is higher in the earlier stages (pure culture stages) than in the final stages of the fermentation process. The earlier fermentation stages are batch fermentors, where excess sugars are present and less aeration is used during the fermentation process. These fermentations are not controlled to the degree that the final fermentations are controlled because the majority of yeast growth occurs in the final fermentation stages. Therefore, there is no economical reason for manufacturers to equip the earlier fermentation stages with process control equipment.

Another potential emission source at yeast manufacturing facilities is the system used to treat process waste waters. If the facility does not use an anaerobic biological treatment system, significant quantities of VOCs could be emitted from this stage of the process. For more information on waste water treatment systems as an emission source of VOCs, please refer to EPA's Control Technology Center document on industrial waste water treatment systems, *Industrial Wastewater Volatile Organic Compound Emissions - Background Information For BACT/LAER*, or see Section 4.3 of AP-42. At facilities manufacturing dry yeast, VOCs may also be emitted from the yeast dryers, but no information is available on the relative quantity of VOC emissions from this source.

9.13.4.4 Controls⁶

Only 1 yeast manufacturing facility uses an add-on pollution control system to reduce VOC emissions from the fermentation process. However, all yeast manufacturers suppress ethanol formation through varying degrees of process control, such as incrementally feeding the molasses mixture to the fermentors so that excess sugars are not present, or supplying sufficient oxygen to the fermentors to optimize the dissolved oxygen content of the liquid in the fermentor. The adequacy of oxygen distribution depends upon the proper design and operation of the aeration and mechanical agitation systems of the fermentor. The distribution of oxygen by the air sparger system to the malt mixture is critical. If oxygen is not being transferred uniformly throughout the malt, then ethanol

will be produced in the oxygen-deficient areas of the fermentor. The type and position of baffles and/or a highly effective mechanical agitation system can ensure proper distribution of oxygen.

A more sophisticated form of process control involves using a continuous monitoring system and feedback control. In such a system, process parameters are monitored, and the information is sent to a computer. The computer is then used to calculate sugar consumption rates through material balance techniques. Based on the calculated data, the computer continuously controls the addition of molasses. This type of system is feasible, but it is difficult to design and implement. Such enhanced process control measures can suppress ethanol formation from 75 to 95 percent.

The 1 facility with add-on control uses a wet scrubber followed by a biological filter. Performance data from this unit suggest an emission control efficiency of better than 90 percent.

9.13.4.5 Emission Factors^{1,6-9}

Table 9.13.4-1 provides emission factors for a typical yeast fermentation process with a moderate degree of process control. The process emission factors in Table 9.13.4-1 were developed from 4 test reports from 3 yeast manufacturing facilities. Separate emission factors are given for intermediate, stock/pitch, and trade fermentations. The emission factors in Table 9.13.4-1 are expressed in units of VOC emitted per fermentor per unit of yeast produced in that fermentor.

In order to use the emission factors for each fermentor, the amount of yeast produced in each fermentor must be known. The following is an example calculation for a typical facility:

Fermentation Stage	Yeast Yield Per Batch, lb (A)	No. Of Batches Processed Per Year, #/yr (B)	Total Yeast Production Per Stage, tons/yr (C = A x B/2,000)	Emission Factor, lb/ton (D)	Emissions, lb ($E = C \times D$)	Percent of Total Emissions
Intermediate	265	156	21	36	756	0.84
Stock	930	208	97	5	485	0.54
Pitch	5,510	208	573	5	2,865	3.18
Trade	33,070	1,040	17,196	5	85,980	95.44
TOTAL	—	-	-	_	90,086	100

In most cases, the annual yeast production per stage will not be available. However, a reasonable estimate can be determined based on the emission factor for the trade fermentor and the total yeast production for the facility. Trade fermentors produce the majority of all VOCs emitted from the facility because of the number of batches processed per year and of the amount of yeast grown in these fermentors. Based on emission test data and process data regarding the number of batches processed per year, 80 to 90 percent of VOCs emitted from fermentation operations are a result of the trade fermentors.

Using either a 2-stage or 4-stage fermentation process has no significant effect on the overall emissions for the facility. Facilities that use the 2-stage process may have larger fermentors or may produce more batches per year than facilities that use a 4-stage process. The main factors affecting emissions are the total yeast production for a facility and the degree of process control used.

Table 9.13.4-1 (Metric And English Units). VOLATILE ORGANIC COMPOUND (VOC) EMISSION FACTORS FOR YEAST MANUFACTURING^a

	VOC ^c				
Emission Point ^b	VOC Emitted Per Stage Per Amount Of Yeast Produced In A Stage, kg VOC/Mg Yeast	VOC Emitted Per Stage Per Amount Of Yeast Produced In A Stage, Ib VOC/ton Yeast			
Fermentation stages ^d					
Flask (F1)	ND	ND			
Pure culture (F2/F3)	ND	ND			
Intermediate (F4) (SCC 3-02-034-04)	18	36			
Stock (F5) (SCC 3-02-034-05)	2.5	5.0			
Pitch (F6) (SCC 3-02-034-06)	2.5	5.0			
Trade (F7) (SCC 3-02-034-07)	2.5	5.0			
Waste treatment (SCC 3-02-034-10)	See Section	4.3 of AP-42			
Drying (SCC 3-02-034-20)	ND	ND			

EMISSION FACTOR RATING: E

^a References 1,6-10. Total VOC as ethanol. SCC = Source Classification Code. ND = no data. F numbers refer to fermentation stages (see Figure 9.13.4-1).

^b Factors are for both dry yeast (SCC 3-02-034-XX) and compressed yeast (SCC 3-02-035-XX).

^c Factors should be used only when plant-specific emission data are not available because of the high degree of emissions variability among facilities and among batches within a facility.

^d Some yeast manufacturing facilities use a 2-stage final fermentation process, and others use a 4-stage final fermentation process. Factors for each stage cannot be summed to determine an overall emission factor for a facility, since they are based on yeast yields in each fermentor rather than total yeast production. Total yeast production for a facility equals only the yeast yield from the trade fermentations. Note that CO_2 is also a byproduct of fermentation, but no data are available on the amount emitted.

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9.14 Tobacco Products

[Work In Progress]

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9.15 Leather Tanning

[Work In Progress]

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9.15 Leather Tanning

9.15.1 General¹⁻⁴

Leather tanning is the process of converting raw hides or skins into leather. Hides and skins have the ability to absorb tannic acid and other chemical substances that prevent them from decaying, make them resistant to wetting, and keep them supple and durable. The surface of hides and skins contains the hair and oil glands and is known as the grain side. The flesh side of the hide or skin is much thicker and softer. The three types of hides and skins most often used in leather manufacture are from cattle, sheep, and pigs.

Tanning is essentially the reaction of collagen fibers in the hide with tannins, chromium, alum, or other chemical agents. The most common tanning agents used in the U. S. are trivalent chromium and vegetable tannins extracted from specific tree barks. Alum, syntans (man-made chemicals), formaldehyde, glutaraldehyde, and heavy oils are other tanning agents.

There are approximately 111 leather tanning facilities in the United States. However, not every facility may perform the entire tanning or finishing process. Leather tanning and finishing facilities are most prevalent in the northeast and midwest states; Pennsylvania, Massachusetts, New York, and Wisconsin account for almost half of the facilities. The number of tanneries in the United States has significantly decreased in the last 40 years due to the development of synthetic substitutes for leather, increased leather imports, and environmental regulation.

9.15.2 Process Description^{1-2,5-6}

Although the title of this section is "Leather Tanning", the entire leathermaking process is considered here, not just the actual tanning step. "Leather tanning" is a general term for the numerous processing steps involved in converting animal hides or skins into finished leather. Production of leather by both vegetable tanning and chrome tanning is described below. Chrome tanning accounts for approximately 90 percent of U. S. tanning production. Figure 9.15-1 presents a general flow diagram for the leather tanning and finishing process. Trimming, soaking, fleshing, and unhairing, the first steps of the process, are referred to as the beamhouse operations. Bating, pickling, tanning, wringing, and splitting are referred to as tanyard processes. Finishing processes include conditioning, staking, dry milling, buffing, spray finishing, and plating.

9.15.2.1 Vegetable Tanning -

Heavy leathers and sole leathers are produced by the vegetable tanning process, the oldest of any process in use in the leather tanning industry. The hides are first trimmed and soaked to remove salt and other solids and to restore moisture lost during curing. Following the soaking, the hides are fleshed to remove the excess tissue, to impart uniform thickness, and to remove muscles or fat adhering to the hide. Hides are then dehaired to ensure that the grain is clean and the hair follicles are free of hair roots. Liming is the most common method of hair removal, but thermal, oxidative, and chemical methods also exist. The normal procedure for liming is to use a series of pits or drums containing lime liquors (calcium hydroxide) and sharpening agents. Following liming, the hides are dehaired by scraping or by machine. Deliming is then performed to make the skins receptive to the vegetable tanning. Bating, an enzymatic action for the removal of unwanted hide components after liming, is performed to impart softness, stretch, and flexibility to the leather. Bating and deliming are usually performed together by placing the hides in an aqueous solution of an ammonium salt and proteolytic



Figure 9.15-1. General flow diagram for leather tanning and finishing process.

enzymes at 27° to 32°C (80° to 90° F). Pickling may also be performed by treating the hide with a brine solution and sulfuric acid to adjust the acidity for preservation or tanning.

In the vegetable tanning process, the concentration of the tanning materials starts out low and is gradually increased as the tannage proceeds. It usually takes 3 weeks for the tanning material to penetrate to the center of the hide. The skins or hides are then wrung and may be cropped or split; heavy hides may be retanned and scrubbed. For sole leather, the hides are commonly dipped in vats or drums containing sodium bicarbonate or sulfuric acid for bleaching and removal of surface tannins. Materials such as lignosulfate, corn sugar, oils, and specialty chemicals may be added to the leather. The leather is then set out to smooth and dry and may then undergo further finishing steps. However, a high percentage of vegetable-tanned leathers do not undergo retanning, coloring, fatliquoring, or finishing.

Leather may be dried by any of five common methods. Air drying is the simplest method. The leather is hung or placed on racks and dried by the natural circulation of air around it. A toggling unit consists of a number of screens placed in a dryer that has controlled temperature and humidity. In a pasting unit, leathers are pasted on large sheets of plate glass, porcelain, or metal and sent through a tunnel dryer with several controlled temperature and humidity zones. In vacuum drying, the leather is spread out, grain down, on a smooth surface to which heat is applied. A vacuum hood is placed over the surface, and a vacuum is applied to aid in drying the leather. High-frequency drying involves the use of a high frequency electromagnetic field to dry the leather.

9.15.2.2 Chrome Tanning -

Chrome-tanned leather tends to be softer and more pliable than vegetable-tanned leather, has higher thermal stability, is very stable in water, and takes less time to produce than vegetable-tanned leather. Almost all leather made from lighter-weight cattle hides and from the skin of sheep, lambs, goats, and pigs is chrome tanned. The first steps of the process (soaking, fleshing, liming/dehairing, deliming, bating, and pickling) and the drying/finishing steps are essentially the same as in vegetable tanning. However, in chrome tanning, the additional processes of retanning, dyeing, and fatliquoring are usually performed to produce usable leathers and a preliminary degreasing step may be necessary when using animal skins, such as sheepskin.

Chrome tanning in the United States is performed using a one-bath process that is based on the reaction between the hide and a trivalent chromium salt, usually a basic chromium sulfate. In the typical one-bath process, the hides are in a pickled state at a pH of 3 or lower, the chrome tanning materials are introduced, and the pH is raised. Following tanning, the chrome tanned leather is piled down, wrung, and graded for the thickness and quality, split into flesh and grain layers, and shaved to the desired thickness. The grain leathers from the shaving machine are then separated for retanning, dyeing, and fatliquoring. Leather that is not subject to scuffs and scratches can be dyed on the surface only. For other types of leather (i. e., shoe leather) the dye must penetrate further into the leather. Typical dyestuffs are aniline-based compounds that combine with the skin to form an insoluble compound.

Fatliquoring is the process of introducing oil into the skin before the leather is dried to replace the natural oils lost in beamhouse and tanyard processes. Fatliquoring is usually performed in a drum using an oil emulsion at temperatures of about 60° to 66° C (140° to 150° F) for 30 to 40 minutes. After fatliquoring, the leather is wrung, set out, dried, and finished. The finishing process refers to all the steps that are carried out after drying.

9.15.2.3 Leather Finishing

Leathers may be finished in a variety of ways: buffed with fine abrasives to produce a suede finish; waxed, shellacked, or treated with pigments, dyes, and resins to achieve a smooth, polished surface and the desired color; or lacquered with urethane for a glossy patent leather. Water-based or solvent-based finishes may also be applied to the leather. Plating is then used to smooth the surface of the coating materials and bond them to the grain. Hides may also be embossed.

9.15.3 Emissions and Controls^{2,4,6}

There are several potential sources of air emissions in the leather tanning and finishing industry. Emissions of VOC may occur during finishing processes, if organic solvents are used, and during other processes, such as fatliquoring and drying. If organic degreasing solvents are used during soaking in suede leather manufacture, these VOC may also evaporate to the atmosphere. Many tanneries are implementing water-based coatings to reduce VOC emissions. Control devices, such as thermal oxidizers, are used less frequently to reduce VOC emissions. Ammonia emissions may occur during some of the wet processing steps, such as deliming and unhairing, or during drying if ammonia is used to aid dye penetration during coloring. Emissions of sulfides may occur during liming/unhairing and subsequent processes. Also, alkaline sulfides in tannery wastewater can be converted to hydrogen sulfide if the pH is less than 8.0, resulting in release of this gas. Particulate emissions may occur during shaving, drying, and buffing; they are controlled by dust collectors or scrubbers.

Chromium emissions may occur from chromate reduction, handling of basic chromic sulfate powder, and from the buffing process. No air emissions of chromium occur during soaking or drying. At plants that purchase chromic sulfate in powder form, dust containing trivalent chromium may be emitted during storage, handling, and mixing of the dry chromic sulfate. The buffing operation also releases particulates, which may contain chromium. Leather tanning facilities, however, have not been viewed as sources of chromium emissions by the States in which they are located.

References for Section 9.15

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9.16 Agricultural Wind Erosion

[Work In Progress]

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10. WOOD PRODUCTS INDUSTRY

Wood processing in this industry involves the conversion of trees into useful consumer products and/or building materials such as paper, charcoal, treated and untreated lumber, plywood, particle board, wafer board, and medium density fiber board. During the conversion processes, the major pollutants of concern are particulate, PM-10, and volatile organic compounds. There also may be speciated organic compounds that may be toxic or hazardous.

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10.1 Lumber

[Work In Progress]

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10.2 Chemical Wood Pulping

10.2.1 General

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers together. The 4 processes principally used in chemical pulping are kraft, sulfite, neutral sulfite semichemical (NSSC), and soda. The first 3 display the greatest potential for causing air pollution. The kraft process alone accounts for over 80 percent of the chemical pulp produced in the United States. The choice of pulping process is determined by the desired product, by the wood species available, and by economic considerations.

10.2.2 Kraft Pulping

10.2.2.1 Process Description¹ -

The kraft pulping process (see Figure 10.2-1) involves the digesting of wood chips at elevated temperature and pressure in "white liquor", which is a water solution of sodium sulfide and sodium hydroxide. The white liquor chemically dissolves the lignin that binds the cellulose fibers together.

There are 2 types of digester systems, batch and continuous. Most kraft pulping is done in batch digesters, although the more recent installations are of continuous digesters. In a batch digester, when cooking is complete, the contents of the digester are transferred to an atmospheric tank usually referred to as a blow tank. The entire contents of the blow tank are sent to pulp washers, where the spent cooking liquor is separated from the pulp. The pulp then proceeds through various stages of washing, and possibly bleaching, after which it is pressed and dried into the finished product. The "blow" of the digester does not apply to continuous digester systems.

The balance of the kraft process is designed to recover the cooking chemicals and heat. Spent cooking liquor and the pulp wash water are combined to form a weak black liquor which is concentrated in a multiple-effect evaporator system to about 55 percent solids. The black liquor is then further concentrated to 65 percent solids in a direct-contact evaporator, by bringing the liquor into contact with the flue gases from the recovery furnace, or in an indirect-contact concentrator. The strong black liquor is then fired in a recovery furnace. Combustion of the organics dissolved in the black liquor provides heat for generating process steam and for converting sodium sulfate to sodium sulfide. Inorganic chemicals present in the black liquor collect as a molten smelt at the bottom of the furnace.

The smelt is dissolved in water to form green liquor, which is transferred to a causticizing tank where quicklime (calcium oxide) is added to convert the solution back to white liquor for return to the digester system. A lime mud precipitates from the causticizing tank, after which it is calcined in a lime kiln to regenerate quicklime.

For process heating, for driving equipment, for providing electric power, etc., many mills need more steam than can be provided by the recovery furnace alone. Thus, conventional industrial boilers that burn coal, oil, natural gas, or bark and wood are commonly used.





Figure 10.2-1. Typical kraft sulfate pulping and recovery process.

10.2-2

10.2.2.2 Emissions And Controls¹⁻⁷ -

Particulate emissions from the kraft process occur largely from the recovery furnace, the lime kiln and the smelt dissolving tank. These emissions are mainly sodium salts, with some calcium salts from the lime kiln. They are caused mostly by carryover of solids and sublimation and condensation of the inorganic chemicals.

Particulate control is provided on recovery furnaces in a variety of ways. In mills with either cyclonic scrubber or cascade evaporator as the direct-contact evaporator, further control is necessary, as these devices are generally only 20 to 50 percent efficient for particulates. Most often in these cases, an electrostatic precipitator (ESP) is employed after the direct-contact evaporator, for an overall particulate control efficiency of from 85 to more than 99 percent. Auxiliary scrubbers may be added at existing mills after a precipitator or a venturi scrubber to supplement older and less efficient primary particulate control devices.

Particulate control on lime kilns is generally accomplished by scrubbers. Electrostatic precipitators have been used in a few mills. Smelt dissolving tanks usually are controlled by mesh pads, but scrubbers can provide further control.

The characteristic odor of the kraft mill is caused by the emission of reduced sulfur compounds, the most common of which are hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide, all with extremely low odor thresholds. The major source of hydrogen sulfide is the direct contact evaporator, in which the sodium sulfide in the black liquor reacts with the carbon dioxide in the furnace exhaust. Indirect contact evaporators can significantly reduce the emission of hydrogen sulfide. The lime kiln can also be a potential source of odor, as a similar reaction occurs with residual sodium sulfide in the lime mud. Lesser amounts of hydrogen sulfide are emitted with the noncondensables of offgases from the digesters and multiple-effect evaporators.

Methyl mercaptan and dimethyl sulfide are formed in reactions with the wood component, lignin. Dimethyl disulfide is formed through the oxidation of mercaptan groups derived from the lignin. These compounds are emitted from many points within a mill, but the main sources are the digester/blow tank systems and the direct contact evaporator.

Although odor control devices, per se, are not generally found in kraft mills, emitted sulfur compounds can be reduced by process modifications and improved operating conditions. For example, black liquor oxidation systems, which oxidize sulfides into less reactive thiosulfates, can considerably reduce odorous sulfur emissions from the direct contact evaporator, although the vent gases from such systems become minor odor sources themselves. Also, noncondensable odorous gases vented from the digester/blow tank system and multiple effect evaporators can be destroyed by thermal oxidation, usually by passing them through the lime kiln. Efficient operation of the recovery furnace, by avoiding overloading and by maintaining sufficient oxygen, residence time, and turbulence, significantly reduces emissions of reduced sulfur compounds from this source as well. The use of fresh water instead of contaminated condensates in the scrubbers and pulp washers further reduces odorous emissions.

Several new mills have incorporated recovery systems that eliminate the conventional directcontact evaporators. In one system, heated combustion air, rather than fuel gas, provides directcontact evaporation. In another, the multiple-effect evaporator system is extended to replace the direct-contact evaporator altogether. In both systems, sulfur emissions from the recovery furnace/direct-contact evaporator can be reduced by more than 99 percent. Sulfur dioxide is emitted mainly from oxidation of reduced sulfur compounds in the recovery furnace. It is reported that the direct contact evaporator absorbs about 75 percent of these emissions, and further scrubbing can provide additional control.

Potential sources of carbon monoxide emissions from the kraft process include the recovery furnace and lime kilns. The major cause of carbon monoxide emissions is furnace operation well above rated capacity, making it impossible to maintain oxidizing conditions.

Some nitrogen oxides also are emitted from the recovery furnace and lime kilns, although amounts are relatively small. Indications are that nitrogen oxide emissions are on the order of 0.5 to 1.0 kilograms per air-dried megagram (kg/Mg) (1 to 2 pounds per air-dried ton [lb/ton]) of pulp produced from the lime kiln and recovery furnace, respectively.⁵⁻⁶

A major source of emissions in a kraft mill is the boiler for generating auxiliary steam and power. The fuels are coal, oil, natural gas, or bark/wood waste. See Chapter 1, "External Combustion Sources", for emission factors for boilers.

Table 10.2-1 presents emission factors for a conventional kraft mill. The most widely used particulate control devices are shown, along with the odor reductions through black liquor oxidation and incineration of noncondensable offgases. Tables 10.2-2, 10.2-3, 10.2-4, 10.2-5, 10.2-6, and 10.2-7 present cumulative size distribution data and size-specific emission factors for particulate emissions from sources within a conventional kraft mill. Uncontrolled and controlled size-specific emission factors⁷ are presented in Figure 10.2-2, Figure 10.2-3, Figure 10.2-4, Figure 10.2-5, Figure 10.2-6, and Figure 10.2-7. The particle sizes are expressed in terms of the aerodynamic diameter in micrometers (μ m).

10.2.3 Acid Sulfite Pulping

10.2.3.1 Process Description -

The production of acid sulfite pulp proceeds similarly to kraft pulping, except that different chemicals are used in the cooking liquor. In place of the caustic solution used to dissolve the lignin in the wood, sulfurous acid is employed. To buffer the cooking solution, a bisulfite of sodium, magnesium, calcium, or ammonium is used. A diagram of a typical magnesium-base process is shown in Figure 10.2-8.

Digestion is carried out under high pressure and high temperature, in either batch mode or continuous digesters, and in the presence of a sulfurous acid/bisulfite cooking liquid. When cooking is completed, either the digester is discharged at high pressure into a blow pit, or its contents are pumped into a dump tank at lower pressure. The spent sulfite liquor (also called red liquor) then drains through the bottom of the tank and is treated and discarded, incinerated, or sent to a plant for recovery of heat and chemicals. The pulp is then washed and processed through screens and centrifuges to remove knots, bundles of fibers, and other material. It subsequently may be bleached, pressed, and dried in papermaking operations.

Because of the variety of cooking liquor bases used, numerous schemes have evolved for heat and/or chemical recovery. In calcium base systems, found mostly in older mills, chemical recovery is not practical, and the spent liquor is usually discharged or incinerated. In ammonium base operations, heat can be recovered by combusting the spent liquor, but the ammonium base is thereby consumed. In sodium or magnesium base operations, the heat, sulfur, and base all may be feasibly recovered.

Table 10.2-1 (Metric And English Units). EMISSION FACTORS FOR KRAFT PULPING^a

EMISSION FACTOR RATING: A

	Туре	Partic	ulate	Sulfur (SC	Dioxide D ₂)	Carbon N (C	fonoxide O)	Hydroger (S ^r	n Sulfide ^m)	RSH, RS (S'	R, RSSR ")
Source	Control	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Digester relief and blow tank	Untreated ^b	ND	ND	ND	ND	ND	ND	0.02	0.03	0.6	1.2
Brown stock washer	Untreated ^b	ND	ND	ND	ND	ND	ND	0.01	0.02	0.2 ^c	0.4 ^c
Multiple effect evaporator	Untreated ^b	ND	ND	ND	ND	ND	ND	0.55	1.1	0.05	0.1
Recovery boiler and direct											
evaporator	Untreated ^d	90	180	3.5	7	5.5	11	6 ^e	12 ^e	1.5°	3°
	Venturi scrubber ^f	24	48	3.5	7	5.5	11	6 ^e	12°	1.5°	3°
	ESP	1	2	3.5	7	5.5	11	6 ^e	12 [°]	1. 5°	3°
	Auxiliary scrubber	1.5 - 7.5 ^g	3 - 15 ^g					6 ^e	12 ^e	1.5°	3°
Noncontact recovery boiler without direct contact evaporator	Untreated ESP	115 1	230 2	ND ND	ND ND	5.5 5.5	11 11	0.05 ^h 0.05 ^h	0.1 ^b 0.1 ^b	ND ND	ND ND
Smelt dissolving tank	Untreated Mesh pad Scrubber	3.5 0.5 0.1	7 1 0.2	0.1 0.1 ND	0.2 0.2 ND	ND ND ND	ND ND ND	0.1 ^j 0.1 ^j 0.1 ^j	0.2 ^j 0.2 ^j 0.2 ^j	0.15 ^j 0.15 ^j 0.15 ^j	0.3 ^j 0.3 ^j 0.3 ^j
Lime kiln	Untreated Scrubber	28	56	0.15	0.3	0.05	0.1	0.25 ^m	0.5 ^m	0.1 ^m	0.2 ^m
	or ESP	0.25	0.5	ND	ND	0.05	0.1	0.25 ^m	0.5 ^m	0.1 ^m	0.2 ^m
Turpentine condenser	Untreated	ND	ND	ND	ND	ND	ND	0.005	0.01	0.25	0.5
Miscellaneous ⁿ	Untreated	ND	ND	ND	ND	ND	ND	ND	ND	0.25	0.5

- ^a References 8-10. Factors expressed in unit weight of air-dried unbleached pulp (ADP). RSH = Methyl mercaptan. RSR = Dimethyl sulfide. RSSR = Dimethyl disulfide. ESP = Electrostatic precipitator. ND = No data.
- ^b If noncondensable gases from these sources are vented to lime kiln, recovery furnace, or equivalent, the reduced sulfur compounds are destroyed.
- ^c Apply with system using condensate as washing medium. When using fresh water, emissions are 0.05 kg/Mg (0.1 lb/ton).
- ^d Apply when cyclonic scrubber or cascade evaporator is used for direct contact evaporation, with no further controls.
- ^e Usually reduced by 50% with black liquor oxidation and can be cut 95 99% when oxidation is complete and recovery furnace is operated optimally.
- ^f Apply when venturi scrubber is used for direct contact evaporation, with no further controls.
- ^g Use 7.5 kg/Mg (15 lb/ton) when auxiliary scrubber follows venturi scrubber, and 1.5 kg/Mg (3 lb/ton) when it follows ESP.
- ^h Apply when recovery furnace is operated optimally to control total reduced sulfur (TRS) compounds.
- ^j Usually reduced to 0.01 g/kg (0.02 lb/ton) ADP when water low in sulfides is used in smelt dissolving tank and associated scrubber.
- ^m Usually reduced to 0.015 g/kg (0.03 lb/ton) ADP with efficient mud washing, optimal kiln operation and added caustic in scrubbing water. With only efficient mud washing and optimal process control, TRS compounds reduced to 0.04 g/kg (0.08 lb/ton) ADP.
- ⁿ Includes knotter vents, brownstock seal tanks, etc. When black liquor oxidation is included, emissions are 0.3 kg/Mg (0.6 lb/ton).

Table 10.2-2 (Metric Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A RECOVERY BOILER WITH A DIRECT-CONTACT EVAPORATOR AND AN ESP^a

Portigulato Siza	Cumulative State	Mass % ≤ d Size	Cumulative Emission Factor (kg/Mg of Air-Dried Pulp)		
μm)	Uncontrolled	Controlled	Uncontrolled	Controlled	
15	95.0	ND	86	ND	
10	93.5	ND	84	ND	
6	92.2	68.2	83	0.7	
2.5	83.5	53.8	75	0.5	
1.25	56.5	40.5	51	0.4	
1.00	45.3	34.2	41	0.3	
0.625	26.5	22.2	24	0.2	
Total	100	100	90	1.0	

EMISSION FACTOR RATING: C

^aReference 7. ND = no data.



Figure 10.2-2. Cumulative particle size distribution and size-specific emission factors for recovery boiler with direct-contact evaporator and ESP.

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Wood Products Industry

Table 10.2-3 (Metric Units).CUMULATIVE PARTICLE SIZE DISTRIBUTION ANDSIZE-SPECIFIC EMISSION FACTORS FOR A RECOVERY BOILER WITHOUT A
DIRECT-CONTACT EVAPORATOR BUT WITH AN ESPa

Darticulata Siza	Cumulative State	Mass % ≤ d Size	Cumulative En (kg/Mg of Air	nission Factor r-Dried Pulp)
μm)	Uncontrolled	Controlled	Uncontrolled	Controlled
15	ND	78.8	ND	0.8
10	ND	74.8	ND	0.7
6	ND	71.9	ND	0.7
2.5	78.0	67.3	90	0.6
1.25	40.0	51.3	46	0.5
1.00	30.0	42.4	35	0.5
0.625	17.0	29.6	20	0.3
Total	100	100	115	1.0

EMISSION FACTOR RATING: C

^aReference 7. ND = no data.



Figure 10.2-3. Cumulative particle size distribution and size-specific emission factors for recovery boiler without direct-contact evaporator but with ESP.

EMISSION FACTORS

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Table 10.2-4 (Metric Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A LIME KILN WITH A VENTURI SCRUBBER^a

Portioulote Size	Cumulative State	Mass % ≤ 1 Size	Cumulative Emission Factor (kg/Mg of Air-Dried Pulp)		
μm)	Uncontrolled	Controlled	Uncontrolled	Controlled	
15	27.7	98.9	7.8	0.24	
10	16.8	98.3	4.7	0.24	
6	13.4	98.2	3.8	0.24	
2.5	10.5	96.0	2.9	0.24	
1.25	8.2	85.0	2.3	0.21	
1.00	7.1	78.9	2.0	0.20	
0.625	3.9	54.3	1.1	0.14	
Total	100	100	28.0	0.25	

EMISSION FACTOR RATING: C

^aReference 7.



Figure 10.2-4. Cumulative particle size distribution and size-specific emission factors for lime kiln with venturi scrubber.

Table 10.2-5 (Metric Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A LIME KILN WITH AN ESP^a

Dantiaulata Siza	Cumulative State	Mass % ≤ d Size	Cumulative Emission Factor (kg/Mg of Air-Dried Pulp)		
(μm)	Uncontrolled	Controlled	Uncontrolled	Controlled	
15	27.7	91.2	7.8	0.23	
10	16.8	88 <i>.5</i>	4.7	0.22	
6	13.4	86.5	3.8	0.22	
2.5	10.5	83.0	2.9	0.21	
1.25	8.2	70.2	2.3	0.18	
1.00	7.1	62.9	2.0	0.16	
0.625	3.9	46.9	1.1	0.12	
Total	100	100	28.0	0.25	

EMISSION FACTOR RATING: C

^aReference 7.



Figure 10.2-5. Cumulative particle size distribution and size-specific emission factors for lime kiln with ESP.

Table 10.2-6 (Metric Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A SMELT DISSOLVING TANK WITH A PACKED TOWER^a

Portigulata Siza	Cumulative State	Mass % ≤ 1 Size	Cumulative Emission Factor (kg/Mg of Air-Dried Pulp)		
μm)	Uncontrolled	Controlled	Uncontrolled	Controlled	
15	90.0	95.3	3.2	0.48	
10	88.5	95.3	3.1	0.48	
6	87.0	94.3	3.0	0.47	
2.5	73.0	85.2	2.6	0.43	
1.25	47.5	63.8	1.7	0.32	
1.00	40.0	54.2	1.4	0.27	
0.625	25.5	34.2	0.9	0.17	
Total	100	100	3.5	0.50	

EMISSION FACTOR RATING: C

^aReference 7.



Figure 10.2-6. Cumulative particle size distribution and size-specific emission factors for smelt dissolving tank with packed tower.

Table 10.2-7 (Metric Units). CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR A SMELT DISSOLVING TANK WITH A VENTURI SCRUBBER^a

Particulate Size	Cumulative State	Mass % ≤ d Size	Cumulative Emission Factor (kg/Mg of Air-Dried Pulp)		
μm)	Uncontrolled	Controlled	Uncontrolled	Controlled	
15	90.0	89.9	3.2	0.09	
10	88.5	89.5	3.1	0.09	
6	87.0	88.4	3.0	0.09	
2.5	73.0	81.3	2.6	0.08	
1.25	47.5	63.5	1.7	0.06	
1.00	40.0	54.7	1.4	0.06	
0.625	25.5	38.7	0.9	0.04	
Total	100	100	3.5	0.09	

EMISSION FACTOR RATING: C

^aReference 7.



Figure 10.2-7. Cumulative particle size distribution and size-specific emission factors for smelt dissolving tank with venturi scrubber.



Figure 10.2-8. Simplified process flow diagram of magnesium-base process employing chemical and heat recovery.

WEAK RED LIQUOR

LIQUOR HEATER

WEAK RED

LIQUOR
If recovery is practiced, the spent (weak) red liquor (which contains more than half of the raw materials as dissolved organic solids) is concentrated in a multiple-effect evaporator and a directcontact evaporator to 55 to 60 percent solids. This strong liquor is sprayed into a furnace and burned, producing steam to operate the digesters, evaporators, etc. and to meet other power requirements.

When magnesium base liquor is burned, a flue gas is produced from which magnesium oxide is recovered in a multiple cyclone as fine white power. The magnesium oxide is then water slaked and is used as circulating liquor in a series of venturi scrubbers, which are designed to absorb sulfur dioxide from the flue gas and to form a bisulfite solution for use in the cook cycle. When sodium base liquor is burned, the inorganic compounds are recovered as a molten smelt containing sodium sulfide and sodium carbonate. This smelt may be processed further and used to absorb sulfur dioxide from the flue gas and sulfur burner. In some sodium base mills, however, the smelt may be sold to a nearby kraft mill as raw material for producing green liquor.

If liquor recovery is not practiced, an acid plant is necessary of sufficient capacity to fulfill the mill's total sulfite requirement. Normally, sulfur is burned in a rotary or spray burner. The gas produced is then cooled by heat exchangers and a water spray and is then absorbed in a variety of different scrubbers containing either limestone or a solution of the base chemical. Where recovery is practiced, fortification is accomplished similarly, although a much smaller amount of sulfur dioxide must be produced to make up for that lost in the process.

10.2.3.2 Emissions And Controls¹¹ -

Sulfur dioxide (SO_2) is generally considered the major pollutant of concern from sulfite pulp mills. The characteristic "kraft" odor is not emitted because volatile reduced sulfur compounds are not products of the lignin/bisulfite reaction.

A major SO_2 source is the digester and blow pit (dump tank) system. Sulfur dioxide is present in the intermittent digester relief gases, as well as in the gases given off at the end of the cook when the digester contents are discharged into the blow pit. The quantity of sulfur dioxide evolved and emitted to the atmosphere in these gas streams depends on the pH of the cooking liquor, the pressure at which the digester contents are discharged, and the effectiveness of the absorption systems employed for SO_2 recovery. Scrubbers can be installed that reduce SO_2 from this source by as much as 99 percent.

Another source of sulfur dioxide emissions is the recovery system. Since magnesium, sodium, and ammonium base recovery systems all use absorption systems to recover SO_2 generated in recovery furnaces, acid fortification towers, multiple effect evaporators, etc., the magnitude of SO_2 emissions depends on the desired efficiency of these systems. Generally, such absorption systems recover better than 95 percent of the sulfur so it can be reused.

The various pulp washing, screening, and cleaning operations are also potential sources of SO_2 . These operations are numerous and may account for a significant fraction of a mill's SO_2 emissions if not controlled.

The only significant particulate source in the pulping and recovery process is the absorption system handling the recovery furnace exhaust. Ammonium base systems generate less particulate than do magnesium or sodium base systems. The combustion productions are mostly nitrogen, water vapor, and sulfur dioxide.

Auxiliary power boilers also produce emissions in the sulfite pulp mill, and emission factors for these boilers are presented in Chapter 1, "External Combustion Sources". Table 10.2-8 contains emission factors for the various sulfite pulping operations.

10.2.4 Neutral Sulfite Semichemical (NSSC) Pulping

10.2.4.1 Process Description^{9,12-14} -

In this method, wood chips are cooked in a neutral solution of sodium sulfite and sodium carbonate. Sulfite ions react with the lignin in wood, and the sodium bicarbonate acts as a buffer to maintain a neutral solution. The major difference between all semichemical techniques and those of kraft and acid sulfite processes is that only a portion of the lignin is removed during the cook, after which the pulp is further reduced by mechanical disintegration. This method achieves yields as high as 60 to 80 percent, as opposed to 50 to 55 percent for other chemical processes.

The NSSC process varies from mill to mill. Some mills dispose of their spent liquor, some mills recover the cooking chemicals, and some, when operated in conjunction with kraft mills, mix their spent liquor with the kraft liquor as a source of makeup chemicals. When recovery is practiced, the involved steps parallel those of the sulfite process.

10.2.4.2 Emissions And Controls^{9,12-14} -

Particulate emissions are a potential problem only when recovery systems are involved. Mills that do practice recovery but are not operated in conjunction with kraft operations often utilize fluidized bed reactors to burn their spent liquor. Because the flue gas contains sodium sulfate and sodium carbonate dust, efficient particulate collection may be included for chemical recovery.

A potential gaseous pollutant is sulfur dioxide. Absorbing towers, digester/blower tank systems, and recovery furnaces are the main sources of SO_2 , with amounts emitted dependent upon the capability of the scrubbing devices installed for control and recovery.

Hydrogen sulfide can also be emitted from NSSC mills which use kraft type recovery furnaces. The main potential source is the absorbing tower, where a significant quantity of hydrogen sulfite is liberated as the cooking liquor is made. Other possible sources, depending on the operating conditions, include the recovery furnace, and in mills where some green liquor is used in the cooking process, the digester/blow tank system. Where green liquor is used, it is also possible that significant quantities of mercaptans will be produced. Hydrogen sulfide emissions can be eliminated if burned to sulfur dioxide before the absorbing system.

Because the NSSC process differs greatly from mill to mill, and because of the scarcity of adequate data, no emission factors are presented for this process.

Table 10.2-8.	(Metric And English Units).	EMISSION FACTORS FOR SULFITE PULPING

				Emission	n Factor ^b		
			Partice	ılate	Sulfur D	vioxide	EMISSION
Source	Base	Control	kg/ADUMg	lb/ADUT	kg/ADUMg	lb/ADUT	RATING
Digester/blow pit or dump tank ^c	All	None	Neg	Neg	5 to 35	10 to 70	С
	MgO	Process change ^d	Neg	Neg	1 to 3	2 to 6	с
	MgO	Scrubber	Neg	Neg	0.5	1	В
	MgO	Process change and scrubber	Neg	Neg	0.1	0.2	В
	MgO	All exhaust vented through recovery system	Neg	Neg	0	0	A
	NH ₃	Process change	Neg	Neg	12.5	25	D
	NH3	Process change and scrubber	Neg	Neg	0.2	0.4	В
	Na	Process change and scrubber	Neg	Neg	1	2	С
	Ca	Unknown	Neg	Neg	33.5	67	С
Recovery system ^e	MgO	Multicyclone and venturi scrubbers	1	2	4.5	9	A
	NH3	Ammonia absorption and mist eliminator	0.35	0.7	3.5	7	В
	Na	Sodium carbonate scrubber	2	4	1	2	С
Acid plant ^f	NH ₃	Scrubber	Neg	Neg	0.2	0.3	С
	Na	Unknown ^g	Neg	Neg	0.1	0.2	D
	Ca	Jensen scrubber	Neg	Neg	4	8	С
Other ^h	All	None	Neg	Neg	6	12	D

^a Reference 11. All factors represent long term average emissions. ADUMg = Air-dried unbleached megagram. ADUT = Air-dried unbleached ton. Neg = negligible.
 ^b Expressed as kg (lb) of pollutant/air dried unbleached Mg (ton) of pulp.

Table 10.2-8 (cont.).

- ^c Factors represent emissions after cook is completed and when digester contents are discharged into blow pit or dump tank. Some relief gases are vented from digester during cook cycle, but these are usually transferred to pressure accumulators and SO₂ herein reabsorbed for use in cooking liquor. In some mills, actual emissions will be intermittent and for short periods.
- ^d May include such measures as raising cooking liquor pH (thereby lowering free SO₂), relieving digester pressure before contents discharge, and pumping out digester contents instead of blowing out.
- ^e Recovery system at most mills is closed and includes recovery furnace, direct contact evaporator, multiple effect evaporator, acid fortification tower, and SO₂ absorption scrubbers. Generally only one emission point for entire system. Factors include high SO₂ emissions during periodic purging of recovery systems.
- ^f Necessary in mills with insufficient or nonexistent recovery systems.
- ^g Control is practiced, but type of system is unknown.
- ^h Includes miscellaneous pulping operations such as knotters, washers, screens, etc.

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10.3 Pulp Bleaching

[Work In Progress]

10.4 Papermaking

[Work In Progress]

10.5 Plywood

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[Work In Progress]

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10.6 Reconstituted Wood Products

- 10.6.1 Waferboard And Oriented Strand Board
- 10.6.2 Particleboard
- 10.6.3 Medium Density Fiberboard

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10.6.1 Waferboard And Oriented Strand Board

[Work In Progress]

10.6.2 Particleboard

[Work In Progress]

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10.6.3 Medium Density Fiberboard

[Work In Progess]

10.7 Charcoal

10.7.1 Process Description¹⁻⁴

Charcoal is the solid carbon residue following the pyrolysis (carbonization or destructive distillation) of carbonaceous raw materials. Principal raw materials are medium to dense hardwoods such as beech, birch, hard maple, hickory, and oak. Others are softwoods (primarily long leaf and slash pine), nutshells, fruit pits, coal, vegetable wastes, and paper mill residues. Charcoal is used primarily as a fuel for outdoor cooking. In some instances, its manufacture may be considered as a solid waste disposal technique. Many raw materials for charcoal manufacture are wastes, as noted. Charcoal manufacture is also used in forest management for disposal of refuse.

Recovery of acetic acid and methanol byproducts was initially responsible for stimulating the charcoal industry. As synthetic production of these chemicals became commercialized, recovery of acetic acid and methanol became uneconomical.

Charcoal manufacturing kilns generally can be classified as either batch or continuous multiple hearth kilns; continuous multiple hearth kilns are more commonly used than are batch kilns. Batch units such as the Missouri-type charcoal kiln (Figure 10.7-1) are small manually-loaded and -unloaded kilns producing typically 16 megagrams (Mg) (17.6 tons) of charcoal during a 3-week cycle. Continuous units (Figure 10.7-2) produce an average of 2.5 Mg per hour (Mg/hr) (2.75 tons per hour [tons/hr]) of charcoal. During the manufacturing process, the wood is heated, driving off water and highly volatile organic compounds (VOC). Wood temperature rises to approximately 275°C (527°F), and the VOC distillate yield increases. At this point, external application of heat is no longer required because the carbonization reactions become exothermic. At 350°C (662°F), exothermic pyrolysis ends, and heat is again applied to remove the less volatile tarry materials from the product charcoal.

Fabrication of briquettes from raw material may be either an integral part of a charcoal producing facility, or an independent operation, with charcoal being received as raw material. Figure 10.7-3 presents a flow diagram for charcoal briquette production. Raw charcoal is first crushed to pass through an approximately 3 millimeter (0.12 inch) screen aperture and then stored for briquetting. The charcoal is then mixed with a binder to form a 65 to 70 percent charcoal mixture. Typical binder solutions are 9 to 10 percent by weight solutions of cornstarch, milostarch, or wheatstarch. Sawdust or other materials may be added to obtain faster burning or higher temperatures. Briquettes are then formed in a press and dried at approximately 135°C (275°F) for 3 to 4 hours, resulting in a product with a 5 percent moisture content. This process generates a briquette of approximately 90 percent pyrolysis product.

10.7.2 Emissions And Controls³⁻¹²

There are five types of products and byproducts from charcoal production operations: charcoal, noncondensible gases (carbon monoxide [CO], carbon dioxide [CO₂], methane, and ethane), pyroacids (primarily acetic acid and methanol), tars and heavy oils, and water. With the exception of charcoal, all of these materials are emitted with the kiln exhaust. Product constituents and the distribution of these constituents vary, depending on raw materials and carbonization parameters. Organics and CO are naturally combusted to CO_2 and water before leaving the retort. Because the extent of this combustion varies from plant to plant, emission levels are quite variable. Some of the

Wood Products Industry



Figure 10.7-1. The Missouri-type charcoal kiln.⁷ (Source Classification Code: 3-01-006-03.)

EMISSION FACTORS



Figure 10.7-2. The continuous multiple hearth kiln for charcoal production.⁴ (Source Classification Code: 3-01-006-04.)

Wood Products Industry



Figure 10.7-3. Flow diagram for charcoal briquette production.³ (Source Classification Code: 3-01-006-05.)

10.7-4

EMISSION FACTORS

specific organic compounds that may be found in charcoal kiln emissions include ethane, methane, ethanol, and polycyclic organic matter (POM). If uncombusted, tars may solidify to form PM emissions, and pyroacids may form aerosol emissions.

The charcoal briquetting process is also a potential source of emissions. The crushing, screening, and handling of the dry raw charcoal may produce PM and PM-10 emissions. Briquette pressing and drying may be a source of VOC emissions, depending on the type of binder and other additives used.

Continuous production of charcoal is more amenable to emission control than batch production because emission composition and flow rate are relatively constant. Emissions from continuous multiple hearth charcoal kilns generally are controlled with afterburners. Cyclones, which commonly are used for product recovery, also reduce PM emissions from continuous kilns. Afterburning is estimated to reduce emissions of PM, CO, and VOC by at least 80 percent. Control of emissions from batch-type charcoal kilns is difficult because the process and, consequently, the emissions are cyclic. Throughout a cycle, both the emission composition and flow rate change. Batch kilns do not typically have emission control devices, but some may use after-burners.

Particulate matter emissions from briquetting operations can be controlled with a centrifugal collector (65 percent control) or fabric filter (99 percent control).

Emission factors for criteria pollutant emissions from the manufacture of charcoal are shown in Table 10.7-1. Table 10.7-2 presents factors for emission of organic pollutants from charcoal manufacturing.

Table 10.7-1 EMISSION FACTORS FOR CHARCOAL MANUFACTURING--CRITERIA POLLUTANTS AND CO₂^a

	lb/ton									
Source	Total PM ^b	NO _x	СО	VOC	CO ₂					
Charcoal kiln [°] (SCC 3-01-006-03, -04)	310 ^d	24°	290 ^f	270 ^g	1,100 ^f					
Briquetting ^h (SCC 3-01-006-05)	56 ^r	ND	ND	ND	ND					

EMISSION FACTOR RATING: E

^a Factors represent uncontrolled emissions. SCC = Source Classification Code. ND = no data. Emission factors units are lb/ton of product. One lb/ton = 0.5 kg/Mg.

^b Includes condensibles and consists primarily of tars and oils.

[°] Applicable to both batch and continuous kilns.

^d References 2,6-7.

^e Reference 3. Based on 0.14 percent nitrogen content of wood.

^f References 2,6-7,11.

^g References 2-3,6.

^h For entire briquetting process.

EMISSION FACTOR RATING: E

Source	Pollutant	Emission factor, lb/ton
Charcoal kiln ^b (SCC 3-01-006-3, -04)	Methane [°]	110
	Ethane ^d	52
	Methanol ^e	150
	POM ^f	0.0095

^a Factors represent uncontrolled emissions. SCC = Source Classification Code. Emission factors units are lb/ton of product. One lb/ton = 0.5 kg/Mg.

- ^b Applicable to both batch and continuous kilns.
- ° References 2,6.
- ^d References 3,6.
- ^e Reference 2.
- ^f Reference 7.

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10.8 Wood Preserving

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[Work In Progress]

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11. MINERAL PRODUCTS INDUSTRY

The production, processing, and use of various minerals are characterized by particulate emissions in the form of dust. Frequently, as in the case of crushing and screening, this dust is identical in composition to the material being handled. Emissions occur also from handling and storing the finished product because this material is often dry and fine. Particulate emissions from some of the processes such as quarrying, yard storage, and dust from transport are difficult to control, but most can be reduced by conventional particulate control equipment such as cyclones, scrubbers, and fabric filters. Because of the wide variety in processing equipment and final products, emission levels will range widely.

11.1 Hot Mix Asphalt Plants

11.1.1 General^{1-2,23,42-43}

Hot mix asphalt (HMA) paving materials are a mixture of well-graded, high-quality aggregate (which can include reclaimed asphalt pavement [RAP]) and liquid asphalt cement, which is heated and mixed in measured quantities to produce HMA. Aggregate and RAP (if used) constitute over 92 percent by weight of the total mixture. Aside from the amount and grade of asphalt cement used, mix characteristics are determined by the relative amounts and types of aggregate and RAP used. A certain percentage of fine aggregate (less than 74 micrometers $[\mu m]$ in physical diameter) is required for the production of good quality HMA.

Hot mix asphalt paving materials can be manufactured by: (1) batch mix plants, (2) continuous mix (mix outside drum) plants, (3) parallel flow drum mix plants, and (4) counterflow drum mix plants. This order of listing generally reflects the chronological order of development and use within the HMA industry.

There are approximately 3,600 active asphalt plants in the United States. Of these, approximately 2,300 are batch plants, 1,000 are parallel flow drum mix plants, and 300 are counterflow drum mix plants. About 85 percent of plants being manufactured today are of the counterflow drum mix design, while batch plants and parallel flow drum mix plants account for 10 percent and 5 percent, respectively. Continuous mix plants represent a very small fraction of the plants in use (≤ 0.5 percent) and, therefore, are not discussed further.

An HMA plant can be constructed as a permanent plant, a skid-mounted (easily relocated) plant, or a portable plant. All plants can have RAP processing capabilities. Virtually all plants being manufactured today have RAP processing capability.

Batch Mix Plants -

Figure 11.1-1 shows the batch mix HMA production process. Raw aggregate normally is stockpiled near the plant. The bulk aggregate moisture content typically stabilizes between 3 to 5 percent by weight.

Processing begins as the aggregate is hauled from the storage piles and is placed in the appropriate hoppers of the cold feed unit. The material is metered from the hoppers onto a conveyer belt and is transported into a rotary dryer (typically gas- or oil-fired). Dryers are equipped with flights designed to shower the aggregate inside the drum to promote drying efficiency.

As the hot aggregate leaves the dryer, it drops into a bucket elevator and is transferred to a set of vibrating screens where it is classified into as many as 4 different grades (sizes), and is dropped into individual "hot" bins according to size. To control aggregate size distribution in the final <u>batch</u> mix, the operator opens various hot bins over a weigh hopper until the desired mix and weight are obtained. Reclaimed asphalt pavement may be added at this point, also. Concurrent with the aggregate being weighed, liquid asphalt cement is pumped from a heated storage tank to an asphalt bucket, where it is weighed to achieve the desired aggregate-to-asphalt cement ratio in the final mix.

The aggregate from the weigh hopper is dropped into the mixer (pug mill) and dry-mixed for 6 to 10 seconds. The liquid asphalt is then dropped into the pug mill where it is mixed for an





Figure 11.1-1. General process flow diagram for batch mix asphalt plants.⁴³ (Source Classification Codes in parentheses.)

additional period of time. Total mixing time is usually less than 60 seconds. Then the hot mix is conveyed to a hot storage silo or is dropped directly into a truck and hauled to the job site.

Parallel Flow Drum Mix Plants -

Figure 11.1-2 shows the parallel flow drum mix process. This process is a continuous mixing type process, using proportioning cold feed controls for the process materials. The major difference between this process and the batch process is that the dryer is used not only to dry the material but also to mix the heated and dried aggregates with the liquid asphalt cement. Aggregate, which has been proportioned by size gradations, is introduced to the drum at the burner end. As the drum rotates, the aggregates, as well as the combustion products, move toward the other end of the drum in parallel. Liquid asphalt cement flow is controlled by a variable flow pump electronically linked to the new (virgin) aggregate and RAP weigh scales. The asphalt cement is introduced in the mixing zone midway down the drum in a lower temperature zone, along with any RAP and particulate matter (PM) from collectors.

The mixture is discharged at the end of the drum and is conveyed to either a surge bin or HMA storage silos. The exhaust gases also exit the end of the drum and pass on to the collection system.

Parallel flow drum mixers have an advantage, in that mixing in the discharge end of the drum captures a substantial portion of the aggregate dust, therefore lowering the load on the downstream collection equipment. For this reason, most parallel flow drum mixers are followed only by primary collection equipment (usually a baghouse or venturi scrubber). However, because the mixing of aggregate and liquid asphalt cement occurs in the hot combustion product flow, organic emissions (gaseous and liquid aerosol) may be greater than in other processes.

Counterflow Drum Mix Plants -

Figure 11.1-3 shows a counterflow drum mix plant. In this type of plant, the material flow in the drum is opposite or <u>counterflow</u> to the direction of exhaust gases. In addition, the liquid asphalt cement mixing zone is located behind the burner flame zone so as to remove the materials from direct contact with hot exhaust gases.

Liquid asphalt cement flow is controlled by a variable flow pump which is electronically linked to the virgin aggregate and RAP weigh scales. It is injected into the mixing zone along with any RAP and particulate matter from primary and secondary collectors.

Because the liquid asphalt cement, virgin aggregate, and RAP are mixed in a zone removed from the exhaust gas stream, counterflow drum mix plants will likely have organic emissions (gaseous and liquid aerosol) that are lower than parallel flow drum mix plants. A counterflow drum mix plant can normally process RAP at ratios up to 50 percent with little or no observed effect upon emissions. Today's counterflow drum mix plants are designed for improved thermal efficiencies.

Recycle Processes -

In recent years, the use of RAP has been initiated in the HMA industry. Reclaimed asphalt pavement significantly reduces the amount of virgin rock and asphalt cement needed to produce HMA.

In the reclamation process, old asphalt pavement is removed from the road base. This material is then transported to the plant, and is crushed and screened to the appropriate size for further processing. The paving material is then heated and mixed with new aggregate (if applicable), and the proper amount of new asphalt cement is added to produce a high-quality grade of HMA.





Figure 11.1-3. General process flow diagram for counterflow drum mix asphalt plants.⁴³ (Source Classification Codes in parentheses.)

11.1.2 Emissions And Controls^{23,42-43}

Emission points discussed below refer to Figure 11.1-1 for batch mix asphalt plants, and to Figure 11.1-2 and Figure 11.1-3 for drum mix plants.

Batch Mix Plants -

As with most facilities in the mineral products industry, batch mix HMA plants have 2 major categories of emissions: ducted sources (those vented to the atmosphere through some type of stack, vent, or pipe), and fugitive sources (those not confined to ducts and vents but emitted directly from the source to the ambient air). Ducted emissions are usually collected and transported by an industrial ventilation system having 1 or more fans or air movers, eventually to be emitted to the atmosphere through some type of stack. Fugitive emissions result from process and open sources and consist of a combination of gaseous pollutants and PM.

The most significant source of ducted emissions from batch mix HMA plants is the rotary drum dryer. Emissions from the dryer consist of water as steam evaporated from the aggregate, PM, and small amounts of volatile organic compounds (VOC) of various species (including hazardous air pollutants [HAP]) derived from combustion exhaust gases.

Other potential process sources include the hot-side conveying, classifying, and mixing equipment, which are vented to either the primary dust collector (along with the dryer gas) or to a separate dust collection system. The vents and enclosures that collect emissions from these sources are commonly called "fugitive air" or "scavenger" systems. The scavenger system may or may not have its own separate air mover device, depending on the particular facility. The emissions captured and transported by the scavenger system are mostly aggregate dust, but they may also contain gaseous VOCs and a fine aerosol of condensed liquid particles. This liquid aerosol is created by the condensation of gas into particles during cooling of organic vapors volatilized from the asphalt cement in the mixer (pug mill). The amount of liquid aerosol produced depends to a large extent on the temperature of the asphalt cement and aggregate entering the pug mill. Organic vapor and its associated aerosol are also emitted directly to the atmosphere as process fugitives during truck loadout, from the bed of the truck itself during transport to the job site, and from the asphalt storage tank. In addition to low molecular weight VOCs, these organic emission streams may contain small amounts of polycyclic compounds. Both the low molecular weight VOCs and the polycyclic organic compounds can include HAPs. The ducted emissions from the heated asphalt storage tanks may include VOCs and combustion products from the tank heater.

The choice of applicable control equipment for the dryer exhaust and vent line ranges from dry mechanical collectors to scrubbers and fabric collectors. Attempts to apply electrostatic precipitators have met with little success. Practically all plants use primary dust collection equipment with large diameter cyclones, skimmers, or settling chambers. These chambers are often used as classifiers to return collected material to the hot elevator and to combine it with the drier aggregate. To capture remaining PM, the primary collector effluent is ducted to a secondary collection device. Most plants use either a baghouse or a venturi scrubber for secondary emissions control.

There are also a number of fugitive dust sources associated with batch mix HMA plants, including vehicular traffic generating fugitive dust on paved and unpaved roads, aggregate material handling, and other aggregate processing operations. Fugitive dust may range from 0.1 μ m to more than 300 μ m in aerodynamic diameter. On average, 5 percent of cold aggregate feed is less than 74 μ m (minus 200 mesh). Fugitive dust that may escape collection before primary control generally consists of PM with 50 to 70 percent of the total mass less than 74 μ m. Uncontrolled PM emission

factors for various types of fugitive sources in HMA plants are addressed in Section 13.2.3, "Heavy Construction Operations".

Parallel Flow Drum Mix Plants -

The most significant ducted source of emissions is the rotary drum dryer. Emissions from the drum consist of water as steam evaporated from the aggregate, PM, and small amounts of VOCs of various species (including HAPs) derived from combustion exhaust gases, liquid asphalt cement, and RAP, if utilized. The VOCs result from incomplete combustion and from the heating and mixing of liquid asphalt cement inside the drum. The processing of RAP materials may increase VOC emissions because of an increase in mixing zone temperature during processing.

Once the VOCs cool after discharge from the process stack, some condense to form a fine liquid aerosol or "blue smoke" plume. A number of process modifications or restrictions have been introduced to reduce blue smoke including installation of flame shields, rearrangement of flights inside the drum, adjustments of the asphalt injection point, and other design changes.

Counterflow Drum Mix Plants -

The most significant ducted source of emissions is the rotary drum dryer in a counterflow drum mix plant. Emissions from the drum consist of water as steam evaporated from the aggregate, PM, and small amounts of VOCs of various species (including HAPs) derived from combustion exhaust gases, liquid asphalt cement, and RAP, if used.

Because liquid asphalt cement, aggregate, and sometimes RAP, are mixed in a zone not in contact with the hot exhaust gas stream, counterflow drum mix plants will likely have lower VOC emissions than parallel flow drum mix plants. The organic compounds that are emitted from counterflow drum mix plants are likely to be products of a slight inefficient combustion and can include HAP.

Parallel and Counterflow Drum Mix Plants -

Process fugitive emissions associated with batch plant hot screens, elevators, and the mixer (pug mill) are not present in the drum mix processes. However, there may be slight fugitive VOC emissions from transport and handling of the hot mix from the drum mixer to the storage silo and also from the load-out operations to the delivery trucks. Since the drum process is continuous, these plants must have surge bins or storage silos. The fugitive dust sources associated with drum mix plants are similar to those of batch mix plants with regard to truck traffic and to aggregate material feed and handling operations.

Tables 11.1-1 and 11.1-2 present emission factors for filterable PM and PM-10, condensable PM, and total PM for batch mix HMA plants. The emission factors are based on both the type of control technology employed and the type of fuel used to fire the dryer. Particle size data for batch mix HMA plants, also based on the control technology used, are shown in Table 11.1-3. Tables 11.1-4 and 11.1-5 present filterable PM and PM-10, condensable PM, and total PM emission factors for drum mix HMA plants. The emission factors are based on both the type of control technology employed and the type of fuel used to fire the dryer. Particle size data for drum mix HMA plants, also based on the control technology used, are shown in Table 11.1-6. Tables 11.1-7 and 11.1-8 present emission factors for carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), sulfur dioxide (SO₂), and total organic compounds (TOC) from batch and drum mix plants. Table 11.1-9 presents organic pollutant emission factors for batch plants. Tables 11.1-10 and 11.1-11 present organic pollutant emission factors for drum mix plants. Tables 11.1-12 and 11.1-13 present metal emission factors for batch and drum mix plants, respectively.

		Filtera	ble PM				Conde	nsable PM				Total	PM	
Ргосевв	РМ	EMISSION FACTOR RATING	PM- 10 ^b	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING	Total	EMISSION FACTOR RATING	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING
Natural gas-fired dryer (SCC 3-05-002-01)		.	-						•			• <u></u>	• 	<u> </u>
Uncontrolled	16°	E	2.2	E	0.0017 ^d	D	0.00039 ^d	D	0.0021	D	16	E	2.2	E
Low-energy scrubber ^e	0.039	D	ND		0.0017	D	ND		ND		ND		ND	
Venturi scrubber ^e	0.026	E	ND		ND		ND		ND		ND		ND	
Fabric filter	0.020 ^f	D	0.0080	D	0.00148	D	0.00039 ^h	D	0.0018 ^h	D	0.022 ^j	D	0.0098	D
Oil-fired dryer (SCC 3-05-002-01)														
Uncontrolled	16 ^c	E	2.2	Е	0.0083 ^d	D	ND		0.022 ^d	D	16	Е	2.2	E
Venturi scrubber ^e	0.026	E	ND		0.0083	E	ND		ND		ND		ND	
Fabric filter	0.020 ^e	D	0.0080	D	ND		ND		0.022 ^k	D	0.042 ^m	D	0.030	D

Table 11.1-1 (Metric Units). EMISSION FACTORS FOR BATCH MIX HOT MIX ASPHALT PLANTS^a

^a Factors are kg/Mg of product. Filterable PM emission factors were developed from tests on dryers fired with several different fuels. SCC = Source Classification Code. ND = no data.

^b Particle size data from Reference 23 were used in conjunction with the filterable PM emission factors shown.

^c Reference 5.

^d Although no data are available for uncontrolled condensable PM, values are assumed to be equal to the maximum controlled value measured.

^e Reference 15.

^f References 15,24,40-41.

^g Reference 24.

^h References 24,39.

^j References 15,24,39-41.

^k Reference 39.

^m Reference 40.

Table 11.1-2 (English Units). EMISSION FACTORS FOR BATCH MIX HOT MIX ASPHALT PLANTS^a

		Filterab	le PM			Condensable PM						Total	PM	
Process	РМ	EMISSION FACTOR RATING	PM-1 0 ^b	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING	Total	EMISSION FACTOR RATING	РМ	EMISSION FACTOR RATING	PM- 10	EMISSION FACTOR RATING
Natural gas-fired dryer (SCC 3-05-002-01)														
Uncontrolled	32°	E	4.5	E	0.0033 ^d	D	0.00078 ^d	D	0.0041	D	32	Е	4.5	E
Low-energy scrubber ^e	0.077	D	ND		0.0033	D	ND		ND		ND		ND	
Venturi scrubber ^e	0.052	E	ND		ND		ND		ND		ND		ND	
Fabric filter	0.040 ^f	D	0.016	D	0.00278	D	0.00078 ^g	D	0.0035 ^h	D	0.044 ^j	D	0.020	D
Oil-fired dryer (SCC 3-05-002-01)														
Uncontrolled	32°	E	4.5	E	0.017 ^d	Е	ND		0.045 ^d	D	32	Е	4.5	E
Venturi scrubber ^e	0.052	E	ND		0.017	E	ND		ND		ND		ND	
Fabric filter	0.040°	D	0.016	D	ND		ND		0.045 ^k	D	0.085 ^m	D	0.061	D

^a Factors are lb/ton of product. Filterable PM emission factors were developed from tests on dryers fired with several different fuels.
 SCC = Source Classification Code. ND = no data.
 ^b Particle size data from Reference 23 were used in conjunction with the filterable PM emission factors shown.

^c Reference 5.

^d Although no data are available for uncontrolled condensable PM, values are assumed to be equal to the maximum controlled value measured.

^e Reference 15.

^f References 15,24,40-41.

- ^g Reference 24.
- ^h References 24,39.
- ^j References 15,24,39-41.
- ^k Reference 39.
- ^mReference 40.

Table 11.1-3.SUMMARY OF PARTICLE SIZE DISTRIBUTIONFOR BATCH MIX HOT MIX ASPHALT PLANTS^a

		Cumulative Mass Less Than Or Equal To Stated Size (%) ^c												
Particle Size, µm ^b	Uncontrolled	Cyclone Collectors	Multiple Centrifugal Scrubbers	Gravity Spray Towers	Fabric Filters									
2.5	0.83	5.0	67	21	33									
5.0	3.5	11	74	27	36									
10.0	14	21	80	37	40									
15.0	23	29	83	39	47									
20.0	30	36	84	41	54									

^a Reference 23, Table 3-36. Rounded to two significant figures.

^b Aerodynamic diameter.

^c Applies only to the mass of filterable PM.

Table 11.1-4 (Metric Units). EMISSION FACTORS FOR DRUM MIX HOT MIX ASPHALT PLANTS^a

EMISSION FACTOR RATING: D (except as noted)

	Filterabl	e PM	Condensable PM Total PM ^b			PM ^b	
Process	РМ	PM-10 ^c	Inorganic	Organic	Total	PM	PM-10
Natural gas-fired dryer (SCC 3-05-002-05)							
Uncontrolled	9.4 ^d	2.2	0.014 ^e	0.027 ^f	0.041	9.4	2.2
Venturi scrubber	0.017 ^g	ND	ND	0.0 10 ^f	ND	ND	ND
Fabric filter	0.0070 ^h	0.0022	ND	ND	0.0019 ^j	0.0089	0.0041
Oil-fired dryer (SCC 3-05-002-05)							
Uncontrolled	9.4 ^d	2.2	0.012 ^e	0.0013 ^e	0.013 ^e	9.4	2.2
Venturi scrubber	0.017 ^g	ND	ND	ND	ND	ND	ND
Fabric filter	0.0070 ^h	0.0022	0.012 ^k	0.0013 ^k	0.013 ^k	0.020	0.015

^a Factors are kg/Mg of product. Tests included dryers that were processing reclaimed asphalt pavement (RAP). Because of the limited data available, the effect of RAP processing on emissions could not be determined. Filterable PM emission factors were developed from tests on dryers firing several different fuels. SCC = Source Classification Code. ND = no data.

^b Total PM emission factors are the sum of filterable PM and total condensable PM emission factors. Total PM-10 emission factors are the sum of filterable PM-10 and total condensable PM emission factors.

^c Particle size data from Reference 23 were used in conjunction with the filterable PM emission factors shown.

^d References 31,36-38.

^e Although no emission test data are available for uncontrolled condensible PM, values are assumed to be equal to the maximum controlled value measured.

f References 36-37.

^g References 29,32,36-37,40.

^h References 25-28,31,33,40. EMISSION FACTOR RATING: C.

EMISSION FACTORS

^j Reference 39.

^k References 25,39.

Table 11.1-5 (English Units). EMISSION FACTORS FOR DRUM MIX HOT MIX ASPHALT PLANTS^a

	Filtera	ilterable PM Condensable PM Total PM			PM ^b		
Process	PM	PM-10 ^c	Inorganic	Organic	Total	PM	PM-10
Natural gas-fired dryer (SCC 3-05-002-05)	·						
Uncontrolled	19 ^d	4.3	0.027 ^e	0.054 ^f	0.081	19	4.4
Venturi scrubber	0.033 ^g	ND	ND	0.020 ^f	ND	ND	ND
Fabric filter	0.014 ^h	0.0045	ND	ND	0.0037 ^j	0.018	0.0082
Dryer (oil-fired) (SCC 3-05-002-05)							
Uncontrolled	19 ^d	4.3	0.023 ^e	0.0026 ^e	0.026 ^e	19	4.3
Venturi scrubber	0.033 ^g	ND	ND	ND	ND	ND	ND
Fabric filter	0.014 ^h	0.0045	0.023 ^k	0.0026 ^k	0.026 ^k	0.040	0.031

EMISSION FACTOR RATING: D (except as noted)

^a Factors are lb/ton of product. Tests included dryers that were processing reclaimed asphalt pavement (RAP). Because of the limited data available, the effect of RAP processing on emissions could not be determined. Filterable PM emission factors were developed from tests on dryers firing several different fuels. SCC = Source Classification Code. ND = no data.

^b Total PM emission factors are the sum of filterable PM and total condensable PM emission factors. Total PM-10 emission factors are the sum of filterable PM-10 and total condensable PM emission factors.

^c Particle size data from Reference 23 were used in conjunction with the filterable PM emission factors shown.

^d References 31,36-38.

^e Although no emission test data are available for uncontrolled condensable PM, values are assumed to be equal to the maximum controlled value measured.

^f References 36-37.

^g References 29,32,36-37,40.

^h References 25-28,31,33,40. EMISSION FACTOR RATING: C.

^j Reference 39.

^k References 25,39.

Table 11.1-6. SUMMARY OF PARTICLE SIZE DISTRIBUTION FOR DRUM MIX HOT MIX ASPHALT PLANTS^a

	Cumulative Mass Less Than Or Equal To	o Stated Size (%) ^c
Particle Size, µm ^b	Uncontrolled	Fabric Filters ^d
2.5	5.5	11
10.0	23	32
15.0	27	35

^a Reference 23, Table 3-35. Rounded to two significant figures.

^b Aerodynamic diameter.

^c Applies only to the mass of filterable PM.

^d Includes data from two out of eight tests where about 30% reclaimed asphalt pavement was processed using a split feed process.

Table 11.1-7 (Metric And English Units). EMISSION FACTORS FOR BATCH MIX HOT MIX ASPHALT PLANTS^a

EMISSION FACTOR RATING: D

	C	0	CO ₂		NO _x		SO ₂		тось	
Process	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Natural gas-fired dryer (SCC 3-05-002-01)	0.17 ^c	0.34 ^c	17 ^d	35 ^d	0.013 ^c	0.025 ^c	0.0025°	0.0050 ^e	0.0084 ^f	0.017 ^f
Oil-fired dryer (SCC 3-05-002-01)	0.035 ^e	0.069°	19 ^g	39 ^g	0. 0 84 ^e	0.17 ^e	0.12 ^c	0.24 ^e	0.023 ^f	0. 046^f

^a Factors are kg/Mg and lb/ton of product. Factors are for uncontrolled emissions, unless noted. SCC = Source Classification Code.

^b Factors represent TOC as methane, based on EPA Method 25A test data.

^c References 24,34,39.

^d References 15,24,39.

^e Reference 39. Dryer tested was fired with #6 fuel oil. Dryers fired with other fuel oils will have different SO₂ emission factors.

f References 24,39.

^g References 15,39.

Table 11.1-8 (Metric And English Units).EMISSION FACTORS FOR DRUM MIX
HOT MIX ASPHALT PLANTS^a

EMISSION FACTOR RATING: D

	СО		CC	CO2		NO _x		02	ТОСь	
Process	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Natural gas-fired dryer (SCC 3-05-002-01)	0.028 ^c	0.056 ^c	14 ^d	27 ^d	0.015 ^c	0.030 ^c	0.0017 ^c	0.0033°	0.025 ^c	0.051°
Oil-fired dryer (SCC 3-05-002-01)	0.018 [¢]	0.036 ^e	19 ^f	37 ^f	0.038 ^g	0.075 ^g	0.028 ^g	0.056 ^g	0.035 ^g	0.069 ^g

^a Factors are kg/Mg and lb/ton of product. Factors represent uncontrolled emissions, unless noted. Tests included dryers that were processing reclaimed asphalt pavement (RAP). Because of limited data, the effect of RAP processing on emissions could not be determined.

SCC = Source Classification Code.

^b Factors represent TOC as methane, based on EPA Method 25A test data.

- ^c Reference 39. Includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be smaller than from parallel flow systems. However, the available data are insufficient to accurately quantify the difference in these emissions.
- ^d References 30,39.
- ^e Reference 25.
- ^f References 25-27,29,32-33,39.
- ^g References 25,39. Includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be smaller than from parallel flow systems. However, the available data are insufficient to accurately quantify the difference in these emissions. One of the dryers tested was fired with #2 fuel oil (0.003 kg/Mg [0.006 lb/ton]) and the other dryer was fired with waste oil (0.05 kg/Mg [0.1 lb/ton]). Dryers fired with other fuel oils will have different SO₂ emission factors.

EMISSION FACTORS

Table 11.1-9 (Metric And English Units). EMISSION FACTORS FOR ORGANIC POLLUTANT EMISSIONS FROM BATCH MIX HOT MIX ASPHALT PLANTS^a

	Pollutant		Emission Factor		
Process	CASRN	Name	kg/Mg	lb/ton	Ref. Nos.
Natural gas-fired dryer (SCC 3-05-002-01)	91-57-6	2-Methylnaphthalene ^b	3.8x10 ⁻⁵	7.7x10 ⁻⁵	24,39
	83-32-9	Acenaphthene ^b	6.2x10 ⁻⁷	1.2x10 ⁻⁶	34,39
	208-96-8	Acenaphthylene ^b	4.3x10 ⁻⁷	8.6x10 ⁻⁷	34,39
	75-07-0	Acetaldehyde	0.00032	0.00064	24
	67-64-1	Acetone	0.0032	0.0064	24
	120-12-7	Anthraceneb	1.5x10 ⁻⁷	3.1x10 ⁻⁷	34,39
	100-52-7	Benzaldehyde	6.4x10 ⁻⁵	0.00013	24
	71-43-2	Benzene	0.00017	0.00035	24,39
	56-55-3	Benzo(a)anthracene ^b	2.3x10 ⁻⁹	4.5x10 ⁻⁹	39
	205-9 9- 2	Benzo(b)fluoranthene ^b	2.3x10 ⁻⁹	4.5x10 ⁻⁹	39
	207-08-9	Benzo(k)fluoranthene ^{b,c}	1.2x10 ⁻⁸	2.4x10 ⁻⁸	34
	78-84-2	Butyraldehyde/ Isobutyraldehyde	1.5x10 ⁻⁵	3.0x10 ⁻⁵	24
	218-01-9	Chrysene ^b	3.1x10 ⁻⁹	6.1x10 ⁻⁹	39
	4170-30-3	Crotonaldehyde	1.5x10 ⁻⁵	2.9x10 ⁻⁵	24
	100-41-4	Ethyl benzene	0.0016	0.0033	24,39
	206-44-0	Fluoranthene ^b	1.6x10 ⁻⁷	3.1x10 ⁻⁷	34,39
	86-73-7	Fluorene ^b	9.8x10 ⁻⁷	2.0x10 ⁻⁶	34,39
	50-00-0	Formaldehyde	0.00043	0.00086	24,39
	66-25-1	Hexanal	1.2x10 ⁻⁵	2.4x10 ⁻⁵	24
	74-82-8	Methane	0.0060	0.012	39
	91-20-3	Naphthalene ^b	2.1x10 ⁻⁵	4.2x10 ⁻⁵	34,39
	85-01-8	Phenanthrene ^b	1.6x10 ⁻⁶	3.3x10 ⁻⁶	34,39
	129-00-0	Pyrene ^b	3.1x10 ⁻⁸	6.2x10 ⁻⁸	34,39
	106-51-4	Quinone	0.00014	0.00027	24
	108-88-3	Toluene	0.00088	0.0018	24,39
	1330-20-7	Xylene	0.0021	0.0043	24,39
Oil-fired dryer (SCC 3-05-002-01)	91-57-6	2-Methylnaphthalene ^b	3.0x10 ⁻⁵	6.0x10 ⁻⁵	39
	206-44-0	Fluorantheneb	1.2x10 ⁻⁵	2.4x10 ⁻⁵	39
	50-00-0	Formaldehyde ^c	0.0016	0.0032	39,40
		Methane	0.0022	0.0043	39
	91-20-3	Naphthalene ^b	2.2x10 ⁻⁵	4.5x10 ⁻⁵	39
	85-01-8	Phenanthrene ^{b,c}	1.8x10 ⁻⁵	3.7x10 ⁻⁵	39
L	129-00-0	Pyrene ^b	2.7x10 ⁻⁵	5.5x10 ⁻⁵	39

EMISSION FACTOR RATING: D (except as noted)

^a Factors are kg/Mg and lb/ton of hot mix asphalt produced. Factors represent uncontrolled emissions, unless noted. CASRN = Chemical Abstracts Service Registry Number. SCC = Source Classification Code.

^b Controlled by a fabric filter. Compound is classified as polycyclic organic matter (POM), as defined in the 1990 Clean Air Act Amendments (CAAA).

° EMISSION FACTOR RATING: E.

Table 11.1-10 (Metric And English Units). EMISSION FACTORS FOR ORGANIC POLLUTANT EMISSIONS FROM DRUM MIX HOT MIX ASPHALT PLANTS^a

	Pollutant		Emission Factor		Ref
Process	CASRN	Name	kg/Mg	lb/ton	Nos.
Natural gas- or propane-fired dryer ^b (SCC 3-05-002-05)	91-58-7	2-Chloronaphthalene ^c	8.9x10 ⁻⁷	1.8x10 ⁻⁶	39
	91-57-6	2-Methylnaphthalene ^c	3.7x10 ⁻⁵	7.4x10 ⁻⁵	39
	83-32-9	Acenaphthene ^c	6.4x10 ⁻⁷	1.3x10 ⁻⁶	35,39
	208-96-8	Acenaphthylenec	4.2x10 ⁻⁶	8.4x10 ⁻⁶	35,39
	120-12-7	Anthracenec	1.0x10 ⁻⁷	2.1x10 ⁻⁷	35,39
	71-43-2	Benzene	0.00060	0.0012	39
	56-55-3	Benzo(a)anthracene ^c	1.0x10 ⁻⁷	2.0x10 ⁻⁷	39
	50-32-8	Benzo(a)pyrene ^c	4.6x10 ⁻⁹	9.2x10 ⁻⁹	39
	205-99-2	Benzo(b)fluoranthene ^c	5.1x10 ⁻⁸	1.0x10 ⁻⁷	35,39
	192-97-2	Benzo(e)pyrene ^c	5.2x10 ⁻⁸	1.0x10 ⁻⁷	39
	191-24-2	Benzo(g,h,i)perylene ^c	1.9x10 ⁻⁸	3.9x10 ⁻⁸	39
	207 - 08-9	Benzo(k)fluoranthene ^c	2.6x10 ⁻⁸	5.3x10 ⁻⁸	39
	218-01-9	Chrysene ^c	1.8x10 ⁻⁷	3.5x10 ⁻⁷	39
	53-70-3	Dibenz(a,h)anthracene ^{c,e}	1.3x10 ⁻⁹	2.7x10 ⁻⁹	39
	100-41-4	Ethylbenzene ^e	0.00015	0.00029	39
	206-44-0	Fluoranthenec	3.0x10 ⁻⁷	5.9x10 ⁻⁷	35,39
	86-73-7	Fluorene ^c	2.7x10 ⁻⁶	5.3x10 ⁻⁶	35,39
	50-00-0	Formaldehyde	0.0018	0.0036	35,39
	50-00-0	Formaldehyde ^{d,e}	0.00079	0.0016	40
	193-39-5	Indeno(1,2,3-cd)pyrene ^c	3.6x10 ⁻⁹	7.3x10 ⁻⁹	39
	74-82-8	Methane	0.010	0.021	39
	71-55-6	Methyl chloroform ^e	2.4x10 ⁻⁵	4.8x10 ⁻⁵	35
	91-20-3	Naphthalene ^c	2.4x10 ⁻⁵	4.8x10 ⁻⁵	35,39
	198-55-0	Perylene ^{c,e}	6.2x10 ⁻⁹	1.2x10 ⁻⁸	39
	85-01-8	Phenanthrene ^c	4.2x10 ⁻⁶	8.4x10 ⁻⁶	35,39
	129-00-0	Pyrene ^c	2.3x10 ⁻⁷	4.6x10 ⁻⁷	35,39
	108-88-3	Toluene	0.00010	0.00020	35,39
	1330-20-7	Xylene	0.00020	0.00040	39
Oil-fired dryer ^c (SCC 3-05-002-05)	9 1-57-6	2-Methylnaphthalene ^c	8.5x10 ⁻⁵	0.00017	39
	208-96-8	Acenaphthylene ^c	1.1x10 ⁻⁵	2.2x10 ⁻⁵	39
	75-07-0	Acetaldehyde	0.00065	0.0013	25
	67-64-1	Acetone	0.00042	0.00083	25

EMISSION FACTOR RATING: D (except as noted)

	Pollutant		Emission Factor		Pof
Process	CASRN	Name	kg/Mg	lb/ton	Nos.
	107-02-8	Acrolein	1.3x10 ⁻⁵	2.6x 10 ⁻⁵	25
	120-12-7	Anthracene ^c	1.8x10 ⁻⁶	3.6 x10 ⁻⁶	39
	100-52-7	Benzaldehyde	5.5x10 ⁻⁵	0.00011	25
	71-43-2	Benzene	0.00020	0.00041	25
	78-84-2	Butyraldehyde/Isobutyraldehyde	8.0x10 ⁻⁵	0.00016	25
	4170-30-3	Crotonaldehyde	4.3x10 ⁻⁵	8.6x 10 ⁻⁵	25
	100-41-4	Ethylbenzene	0.00019	0.00038	25
	86-73-7	Fluorene ^c	8.5x10 ⁻⁶	1.7x10 ⁻⁵	39
	50-00-0	Formaldehyde	0.0012	0.0024	25,39
	50-00-0	Formaldehyde ^{d,e}	0.00026	0.00052	40
	66-25-1	Hexanal	5.5x10 ⁻⁵	0.00011	25
	590-86-3	Isovaleraldehyde	1.6x10 ⁻⁵	3.2x10 ⁻⁵	25
	74-82-8	Methane	0.0096	0.020	25,39
	78-93-3	Methyl ethyl ketone	1.0x10 ⁻⁵	2.0x10 ⁻⁵	25
	91-20-3	Naphthalene ^c	0.00016	0.00031	25,39
	85-01-8	Phenanthrene ^c	2.8x10 ⁻⁵	5.5x10 ⁻⁵	39
	123-38-6	Propionaldehyde	6.5x10 ⁻⁵	0.00013	25
	129-00-0	Pyrene ^{c, e}	1.5x10 ⁻⁶	3.0x10 ⁻⁶	39
	106-51-4	Quinone	8.0x10 ⁻⁵	0.00016	25
	108-88-3	Toluene	0.00037	0.00075	25
	110-62-3	Valeraldehyde	3.4x10 ⁻⁵	6.7x10 ⁻⁵	25
	1330-20-7	Xylene	8.2x10 ⁻⁵	0.00016	25

Table 11.1-10 (cont.).

^a Factors are kg/Mg and lb/ton of hot mix asphalt produced. Table includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be less than from parallel flow systems, but the available data are insufficient to quantify accurately the difference in these emissions. CASRN = Chemical Abstracts Service Registry Number. SCC = Source Classification Code.

^b Tests included dryers that were processing reclaimed asphalt pavement (RAP). Because of limited data, the effect of RAP processing on emissions could not be determined.

^c Controlled by a fabric filter. Compound is classified as polycyclic organic matter (POM), as defined in the 1990 Clean Air Act Amendments (CAAA).

^d Controlled by a wet scrubber.

^e EMISSION FACTOR RATING: E
Table 11.1-11 (Metric And English Units). EMISSION FACTORS FOR ORGANIC POLLUTANT EMISSIONS FROM HOT MIX ASPHALT HOT OIL HEATERS^a

		Pollutant	Emission	n Factor
Process	CASRN	Name	kg/L	lb/gal
Hot oil heater fired	83-32-9	Acenaphthene ^b	6.4x10 ⁻⁸	5.3x10 ⁻⁷
with No.2 fuel oil (SCC 3-05-002-08)	208-96-8	A cenaphthylene ^b	2.4x10 ⁻⁸	2.0x10 ⁻⁷
	120-12-7	Anthracene ^b	2.2x10 ⁻⁸	1.8x10 ⁻⁷
	205-99-2	Benzo(b)fluoranthene ^b	1.2x10 ⁻⁸	1.0x10 ⁻⁷
	206-44-0	Fluoranthene ^b	5.3x10 ⁻⁹	4.4x10 ⁻⁸
	86-73-7	Fluorene ^b	3.8x10 ⁻⁹	3.2x10 ⁻⁸
	50-00-0	Formaldehyde	0.0032	0.027
	91-20-3	Naphthalene ^b	2.0x10 ⁻⁶	1.7x10 ⁻⁵
	85-01-8	Phenanthrene ^b	5.9x10 ⁻⁷	4.9x10 ⁻⁶
	129-00-0	Pyrene ^b	3.8x10 ⁻⁹	3.2x10 ⁻⁸
	19408-74-3	1,2,3,7,8,9-HxCDD	9.1x10 ⁻¹⁴	7.6x10 ⁻¹³
	39227-28-6	1,2,3,4,7,8-HxCDD	8.3x10 ⁻¹⁴	6.9x10 ⁻¹³
		HxCDD	7.4×10^{-13}	6.2x10 ⁻¹²
	35822-46-9	1,2,3,4,6,7,8-HpCDD	1.8x10 ⁻¹²	1.5x10 ⁻¹¹
		HpCDD	2.4x10 ⁻¹²	2.0×10^{-11}
	3268-87-9	OCDD	1.9x10 ⁻¹¹	1.6x10 ⁻¹⁰
		TCDF ^b	4.0x10 ⁻¹³	3.3x10 ⁻¹²
		PeCDF ^b	5.8x10 ⁻¹⁴	4.8x10 ⁻¹³
		HxCDF ^b	2.4×10^{-13}	2.0×10^{-12}
		HpCDF ^b	1.2x10 ⁻¹²	9.7x10 ⁻¹²
}	67562-39-4	1,2,3,4,6,7,8-HpCDF	4.2×10^{-13}	3.5x10 ⁻¹²
	39001-02-0	OCDF	1.4x10 ⁻¹²	1.2x10 ⁻¹¹

EMISSION FACTOR RATING: E

^a Reference 34. Factors are kg/L and lb/gal of fuel consumed. Table includes data from both parallel flow and counterflow drum mix dryers. Organic compound emissions from counterflow systems are expected to be less than from parallel flow systems, but available data are insufficient to quantify accurately the difference in these emissions. CASRN = Chemical Abstracts Service Registry Number. SCC = Source Classification Code.

^b Compound is classified as polycyclic organic matter (POM), as defined in the 1990 Clean Air Act Amendments (CAAA).

Table 11.1-12 (Metric And English Units). EMISSION FACTORS FOR METAL EMISSIONS FROM BATCH MIX HOT MIX ASPHALT PLANTS^a

		Emissio	n Factor	
Process	Pollutant	kg/Mg	lb/ton	Ref. Nos.
Dryer (SCC 3-05-002-01)	Arsenic ^b Barium Beryllium ^b	3.3x10 ⁻⁷ 7.3x10 ⁻⁷ 1.1x10 ⁻⁷	6.6x10 ⁻⁷ 1.5x10 ⁻⁶ 2.2x10 ⁻⁷	34,40 24 34
	Cadmium Chromium Copper Hexavalent chromium ^b Lead Manganese Mercury Nickel Selenium ^b Zinc	$\begin{array}{c} 4.2x10^{-7} \\ 4.2x10^{-7} \\ 1.8x10^{-6} \\ 4.9x10^{-9} \\ 3.7x10^{-7} \\ 5.0x10^{-6} \\ 2.3x10^{-7} \\ 2.1x10^{-6} \\ 4.6x10^{-8} \\ 3.4x10^{-6} \\ \end{array}$	$8.4x10^{-7}$ $8.9x10^{-7}$ $3.7x10^{-6}$ $9.7x10^{-9}$ $7.4x10^{-7}$ $9.9x10^{-6}$ $4.5x10^{-7}$ $4.2x10^{-6}$ $9.2x10^{-8}$ $6.8x10^{-6}$	24,34 24 24,34 34 24,34 24,34 34 24,34 34 24,34 34 24,34

EMISSION FACTOR RATING: D (except as noted)

^a Factors are kg/Mg and lb/ton of hot mix asphalt produced. Emissions controlled by a fabric filter. SCC = Source Classification Code.

^b EMISSION FACTOR RATING: E.

Table 11.1-13 (Metric And English Units). EMISSION FACTORS FOR METAL EMISSIONS FROM DRUM MIX HOT MIX ASPHALT PLANTS^a

EMISSION FACTOR RATING: D

		Emission Factor		
Process	Pollutant	kg/Mg	lb/ton	Ref. Nos.
Dryer ^b	Arsenic	5.5x10 ⁻⁷	1.1x10 ⁻⁶	25,35
(SCC 3-05-002-05)	Barium	2.4×10^{-6}	4.8x10 ⁻⁶	25
	Cadmium	2.2×10^{-7}	4.4x10 ⁻⁷	25,35
	Chromium	6.0x10 ⁻⁶	1.2×10^{-5}	25
	Copper	3.1x10 ⁻⁶	6.1x10 ⁻⁶	25
	Lead	1.7x10 ⁻⁶	3.3x10 ⁻⁶	25,35
	Manganese	5.5x10 ⁻⁶	1.1x10 ⁻⁵	25
	Mercury	3.7x10 ⁻⁹	7.3x10 ⁻⁹	35
	Nickel	7.5×10^{-6}	1.5x10 ⁻⁵	25
	Phosphorus	2.8×10^{-5}	5.5x10 ⁻⁵	25
	Silver	7.0×10^{-7}	1.4x10 ⁻⁶	25
	Zinc	2.1x10 ⁻⁵	4.2×10^{-5}	25,35

^a Factors are kg/Mg and lb/ton of hot mix asphalt produced. Emissions controlled by a fabric filter. SCC = Source Classification Code.

^b Feed material includes RAP.

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11.2 Asphalt Roofing

11.2.1 General¹⁻²

The asphalt roofing industry manufactures asphalt-saturated felt rolls, fiberglass and organic (felt-based) shingles, and surfaced and smooth roll roofing. Most of these products are used in roof construction, but small quantities are used in walls and other building applications.

11.2.2 Process Description¹⁻⁴

The production of asphalt roofing products consists of six major operations: (1) felt saturation, (2) coating, (3) mineral surfacing (top and bottom), (4) cooling and drying, (5) product finishing (seal-down strip application, cutting and trimming, and laminating of laminated shingles), and (6) packaging. There are six major production support operations: (1) asphalt storage, (2) asphalt blowing, (3) back surfacing and granule storage, (4) filler storage, (5) filler heating, and (6) filler and coating asphalt mixing. There are two primary roofing substrates: organic (paper felt) and fiberglass. Production of roofing products from the two substrates differ mainly in the elimination of the saturation process when using fiberglass.

Preparation of the asphalt is an integral part of the production of asphalt roofing. This preparation, called "blowing," involves the oxidation of asphalt flux by bubbling air through liquid asphalt flux at 260°C (500°F) for 1 to 10 hours. The amount of time depends on the desired characteristics of the roofing asphalt, such as softening point and penetration rate. Blowing results in an exothermic reaction that requires cooling. Water sprays are applied either internally or externally to the shell of the blowing vessel. A typical plant blows four to six batches per 24-hour day. Blowing may be done in either vertical vessels or in horizontal chambers (both are frequently referred to as "blowing stills"). Inorganic salts such as ferric chloride (FeCl₃) may be used as catalysts to achieve desired properties and to increase the rate of reaction in the blowing still, decreasing the time required for each blow. Blowing operations may be located at oil refineries, asphalt processing plants, or asphalt roofing plants. Figure 11.2-1 illustrates an asphalt blowing operation.

The most basic asphalt roofing product is asphalt-saturated felt. Figure 11.2-2 shows a typical line for the manufacture of asphalt-saturated felt. It consists of a dry felt feed roll, a dry looper section, a saturator spray section (seldom used today), a saturator dipping section, heated drying-in drums, a wet looper, cooling drums, a finish floating looper, and a roll winder.

Organic felt may weigh from approximately 20 to 55 pounds (lb) per 480 square feet (ft^2) (a common unit in the paper industry), depending upon the intended product. The felt is unrolled from the unwind stand onto the dry looper, which maintains a constant tension on the material. From the dry looper, the felt may pass into the spray section of the saturator (not used in all plants), where asphalt at 205 to 250°C (400 to 480°F) is sprayed onto one side of the felt through several nozzles. In the saturator dip section, the saturated felt is drawn over a series of rollers, with the bottom rollers submerged in hot asphalt at 205 to 250°C (400 to 480°F). During the next step, heated drying-in drums and the wet looper provide the heat and time, respectively, for the asphalt to penetrate the felt. The saturated felt then passes through water-cooled rolls onto the finish floating looper, and then is rolled and cut to product size on the roll winder. Three common weights of asphalt felt are approximately 12, 15, and 30 lb per 108 ft² (108 ft² of felt covers exactly 100 ft² of roof).

EMISSION SOURCE	SCC
ASPHALT BLOWING: SATURANT	3-05-001-01
ASPHALT BLOWING, COATING ASPHALT BLOWING (GENERAL)	3-05-001-02 3-05-001-10
FIXED ROOF ASPHALT	
STORAGE TANKS	3-05-001-30, -31
STORAGE TANKS	3-05-001-32, -33



Figure 11.2-1. Asphalt blowing process flow diagram.^{1,4} (SCC = Source Classification Code)

EMISSION FACTORS

EMISSION SOURCE	SCC
DIPPING ONLY SPRATING ONLY DIPPING/SPRATING DIP SATURATOR, DRVING-IN DRUM, WET LOOPER AND COATER DIP SATURATOR, DRVING-IN DRUM, AND COATER DIP SATURATOR, DRVING-IN DRUM, WET LOOPER SPRAT/DIP SATURATOR, DRVING-IN DRUM, WET LOOPER SPRAT/DIP SATURATOR, DRVING-IN DRUM, WET LOOPER	3.05-001-11 3.05-001-12 3.05-001-13 3.05-001-13 3.05-001-18 3.05-001-18 3.05-001-18
COATER, AND STORAGE TANKS FIXED ROOF ASPHALT STORAGE TANKS FLOATING ROOF ASPHALT STORAGE TANKS	3-05-001-30, -31 3-05-001-32, -33



(SCC = Source Classification Code)

The typical process arrangement for manufacturing asphalt shingles, mineral-surfaced rolls, and smooth rolls is illustrated in Figure 11.2-3. For organic products, the initial production steps are similar to the asphalt-saturated felt line. For fiberglass (polyester) products, the initial saturation operation is eliminated although the dry looper is utilized. A process flow diagram for fiberglass shingle and roll manufacturing is presented in Figure 11.2-4. After the saturation process, both organic and fiberglass (polyester) products follow essentially the same production steps, which include a coater, a granule and sand or backing surface applicator, a press section, water-cooled rollers and/or water spray cooling, finish floating looper, and a roll winder (for roll products), or a seal-down applicator and a shingle cutter (for shingles), or a laminating applicator and laminating operation (for laminated shingles), a shingle stacker, and a packaging station.

Saturated felt (from the saturator) or base fiberglass (polyester) substrate enters the coater. Filled asphalt coating at 180 to 205°C (355 to 425°F) is released through a valve onto the top of the mat just as it passes into the coater. Squeeze rollers in the coater apply filled coating to the backside and distribute it evenly to form a thick base coating to which surfacing materials will adhere. Filled asphalt coating is prepared by mixing coating asphalt or modified asphalt at approximately 250°C (480°F) and a mineral stabilizer (filler) in approximately equal proportions. Typically, the filler is dried and preheated at about 120°C (250°F) in a filler heater before mixing with the coating asphalt. Asphalt modifiers can include rubber polymers or olefin polymers. When modified asphalt is used to produce fiberglass roll roofing, the process is similar to the process depicted in Figure 11.2-4 with the following exception: instead of a coater, an impregnation vat is used, and preceding this vat, asphalt, polymers, and mineral stabilizers are combined in mixing tanks.

After leaving the coater, the coated sheet to be made into shingles or mineral-surfaced rolls passes through the granule applicator where granules are fed onto the hot, coated surface. The granules are pressed into the coating as the mat passes around a press roll where it is reversed, exposing the bottom side. Sand, talc, or mica is applied to the back surface and is also pressed into the coating.

After application of the mineral surfacing, the mat is cooled rapidly by water-cooled rolls and/or water sprays and is passed through air pressure-operated press rolls used to embed the granules firmly into the filled coating. The mat then passes through a drying section where it is air dried. After drying, a strip of adhesive (normally asphalt) is applied to the roofing surface. The strip will act to seal the loose edge of the roofing after application to a roof. A finish looper in the line allows continuous movement of the sheet through the preceding operations and serves to further cool and dry the roofing sheet. Roll roofing is completed at this point is and moves to a winder where rolls are formed. Shingles are passed through a cutter, which cuts the sheet into individual shingles. (Some shingles are formed into laminated products by layering the shingle pieces and binding them together with a laminating material, normally a modified asphalt. The laminant is applied in narrow strips to the backside of the sheet.) The finished shingles are stacked and packaged for shipment.

There are several operations that support the asphalt roofing production line. Asphalt (coating and saturant) is normally delivered to the facility by truck and rail and stored in heated storage tanks. Filler (finely divided mineral) is delivered by truck and normally is pneumatically conveyed to storage bins that supply the filler heater. Granules and back surfacing material are brought in by truck or rail and mechanically or pneumatically conveyed to storage bins.

11.2.3 Emissions And Controls

Emissions from the asphalt roofing industry consist primarily of particulate matter (PM) and volatile organic compounds (VOC). Both are emitted from asphalt storage tanks, blowing stills,

EMISSION FACTORS

EMISSION SOURCE	SCC
FELT SATURATION' DIPPING ONLY	3-05-001-03
FELT SATURATION' DIPPING/SPRAYING	3-05-001-04
DIPPING ONLY	3-05-001-11
SPRAYING ONLY	3-05-001-12
DIPPING/SPRAYING	3-05-001-13
DIP SATURATOR, DRYING-IN DRUM, WET LOOPER AND COATER	3-05-001-16
DIP SATURATOR, DRYING-IN DRUM, AND COATER	3-05-001-17
DIP SATURATOR, DRYING-IN DRUM, AND WET LOOPER	3-05-001-18
SPRAYDIP SATURATOR, DRYING-IN DRUM, WET LOOPER	3-05-001-19
COATER, AND STORAGE TANKS FIXED ROOF ASPHALT STORAGE TANKS	3-05-001-30, 31
FLOATING ROOF ASPHALT STORAGE TANKS	3-05-001-32, -33



Figure 11.2-3. Organic shingle and roll manufacturing process flow diagram.^{1,2} (SCC = Source Classification Code)

Mineral Products Industry

EMISSION SOURCE	SCC
FELT SATURATION: DIPPING ONLY FELT SATURATION: DIPPING/SPRAYING DIPPING ONLY SPRAYING ONLY DIPPING/SPRAYING DIP SATURATOR, DRYING-IN DRUM, WET LOOPER, AND COATER DIP SATURATOR, DRYING-IN DRUM, AND COATER DIP SATURATOR, DRYING-IN DRUM, AND WET LOOPER SPRAY/DIP SATURATOR, DRYING-IN DRUM, WET LOOPER SPRAY/DIP SATURATOR, DRYING-IN DRUM, WET LOOPER, COATER, AND STORAGE TANKS FLOATING ROOF ASPHALT STORAGE TANKS	3-05-001-03 3-05-001-04 3-05-001-11 3-05-001-12 3-05-001-13 3-05-001-18 3-05-001-18 3-05-001-18 3-05-001-30-31 3-05-001-32, 33



Figure 11.2-4. Fiberglass shingle and roll manufacturing process flow diagram.^{1,2} (SCC = Source Classification Code)

EMISSION FACTORS

saturators, coater-mixer tanks, and coaters. The PM from these operations is primarily recondensed asphalt fume. Sealant strip and laminant applicators are also sources of small amounts of PM and VOCs. Mineral surfacing operations and materials handling are additional sources of PM. Small amounts of polycyclic organic matter (POM) are also emitted from blowing stills and saturators. Asphalt and filler heaters are sources of typical products of combustion from natural gas or the fuel in use.

A common method for controlling emissions from the saturator, including the wet looper, is to enclose them completely and vent the enclosure to a control device. The coater may be partially enclosed, normally with a canopy-type hood that is vented to a control device. Full enclosure is not always practical due to operating constraints. Fugitive emissions from the saturator or coater may pass through roof vents and other building openings if not captured by enclosures or hoods. Control devices for saturator/coater emissions include low-voltage electrostatic precipitators (ESP), high-energy air filters (HEAF), coalescing filters (mist eliminators), afterburners (thermal oxidation), fabric filters, and wet scrubbers. Blowing operations are controlled by thermal oxidation (afterburners).

Emission factors for filterable PM from the blowing and saturation processes are summarized in Tables 11.2-1 and 11.2-2. Emission factors for total organic compounds (TOC) and carbon monoxide (CO) are shown in Tables 11.2-3 and 11.2-4.

Particulate matter associated with mineral handling and storage operations is captured by enclosures, hoods, or pickup pipes and controlled by fabric filtration (baghouses) with removal efficiencies of approximately 95 to 99 percent. Other control devices that may be used with mineral handling and storage operations are wet scrubbers and cyclones.

In the industry, closed silos and bins are used for mineral storage, so open storage piles are not an emission source. To protect the minerals from moisture pickup, all conveyors that are outside the buildings are covered or enclosed. Fugitive mineral emissions may occur at unloading points depending on the type of equipment used and the mineral handled. The discharge from the conveyor to the silos and bins is normally controlled by a fabric filter (baghouse).

Process	Filterable PM ^b	EMISSION FACTOR RATING
Asphalt blowing: saturant asphalt ^c (SCC 3-05-001-01)	3.3	Е
Asphalt blowing: coating asphalt ^d (SCC 3-05-001-02)	12	E
Asphalt blowing: saturant asphalt with afterburner ^c (SCC 3-05-001-01)	0.14	D
Asphalt blowing: coating asphalt with afterburner ^d (SCC 3-05-001-02)	0.41	D
Shingle saturation: dip saturator, drying-in drum section, wet looper, and coater ^e (SCC 3-05-001-16)	0.60	D
Shingle saturation: dip saturator, drying-in drum section, wet looper, and coater with ESP ^f (SCC 3-05-001-16)	0.016	D
Shingle saturation: dip saturator, drying-in drum section, and wet looper with HEAF ^g (SCC 3-05-001-18)	0.035	D
Shingle saturation: spray/dip saturator, drying-in drum section, wet looper, coater, and storage tanks ^h (SCC 3-05-001-19)	1.6	D
Shingle saturation: spray/dip saturator, drying-in drum section, wet looper, coater, and storage tanks with HEAF ^h (SCC 3-05-001-19)	0.027	D

Table 11.2-1 (Metric Units). EMISSION FACTORS FOR ASPHALT ROOFING^a

.

^a Factors represent uncontrolled emissions unless noted. Emission factors in kg/Mg of shingles produced unless noted. Polycyclic organic matter emissions comprise approximately 0.03% of PM for blowing stills and 1.1% of PM for saturators. SCC = Source Classification Code. ESP = electrostatic precipitator. HEAF = high-energy air filter.

^b As measured using EPA Method 5A. Filterable PM is that PM collected on or prior to the filter, which is heated to 42.2°C (108°F).

^c Reference 10. Saturant blow of 1.5 hours. Expressed as kg/Mg of asphalt processed.

^d Reference 10. Coating blow of 4.5 hours. Expressed as kg/Mg of asphalt processed.

^e References 6-7,9.

^f Reference 6.

^g Reference 9.

^h Reference 8.

Process	Filterable PM ^b	EMISSION FACTOR RATING
Asphalt blowing: saturant asphalt ^c (SCC 3-05-001-01)	6.6	E •
Asphalt blowing: coating asphalt ^d (SCC 3-05-001-02)	24	Е
Asphalt blowing: saturant asphalt with afterburner ^c (SCC 3-05-001-01)	0.27	D
Asphalt blowing: coating asphalt with afterburner ^d (SCC 3-05-001-02)	0.81	D
Shingle saturation: dip saturator, drying-in drum section, wet looper, and coater ^e (SCC 3-05-001-16)	1.2	D
Shingle saturation: dip saturator, drying-in drum section, wet looper, and coater with ESP ^f (SCC 3-05-001-16)	0.032	D
Shingle saturation: dip saturator, drying-in drum section, and wet looper with HEAF ^g (SCC 3-05-001-18)	0.071	D
Shingle saturation: spray/dip saturator, drying-in drum section, wet looper, coater, and storage tanks ^h (SCC 3-05-001-19)	3.2	D
Shingle saturation: spray/dip saturator, drying-in drum section, wet looper, coater, and storage tanks with HEAF ^h (SCC 3-05-001-19)	0.053	D

Table 11.2-2 (English Units). EMISSION FACTORS FOR ASPHALT ROOFING^a

^a Factors represent uncontrolled emissions unless noted. Emission factors in lb/ton of shingles produced unless noted. Polycyclic organic matter emissions comprise approximately 0.03% of PM for blowing stills and 1.1% of PM for saturators. SCC = Source Classification Code. ESP = electrostatic precipitator. HEAF = high-energy air filter.

^b As measured using EPA Method 5A. Filterable PM is that PM collected on or prior to the filter, which is heated to 42.2°C (108°F).

^c Reference 10. Saturant blow of 1.5 hours. Expressed as lb/ton of asphalt processed.

^d Reference 10. Coating blow of 4.5 hours. Expressed as lb/ton of asphalt processed.

^e References 6-7,9.

^f Reference 6.

^g Reference 9.

^h Reference 8.

Duran	Tock	EMISSION FACTOR		EMISSION FACTOR
Process	1000	RATING	0	RATING
Asphalt blowing: saturant asphalt ^d (SCC 3-05-001-01)	0.66	E	ND	
Asphalt blowing: coating asphalt ^d (SCC 3-05-001-02)	1.7	E	ND	
Asphalt blowing: saturant asphalt with afterburner ^c (SCC 3-05-001-01)	0.0022	D	ND	
Asphalt blowing: coating asphalt with afterburner ^d (SCC 3-05-001-02)	0.085	D	ND	
Shingle saturation: dip saturator, drying-in drum section, wet looper, and coater ^e (SCC 3-05-001-16)	0.046	D	ND	
Shingle saturation: dip saturator, drying-in drum section, wet looper, and coater with ESP ^f (SCC 3-05-001-16)	0.049	D	ND	
Shingle saturation: dip saturator, drying-in drum section, and coater ^g (SCC 3-05-001-17)	ND		0.0095	D
Shingle saturation: dip saturator, drying-in drum section, and wet looper with HEAF ^h (SCC 3-05-001-18)	0.047	D	ND	
Shingle saturation: spray/dip saturator, drying-in drum section, wet looper, coater, and storage tanks ^j (SCC 3-05-001-19)	0.13	D	ND	
Shingle saturation: spray/dip saturator, drying-in drum section, wet looper, coater, and storage tanks with HEAF ^j (SCC 3-05-001-19)	0.16	D	ND	
Asphalt blowing ^k (SCC 3-05-001-10)	ND		0.14	E
Asphalt blowing with afterburner ^k (SCC 3-05-001-10)	ND		1.9	E

Table 11.2-3 (Metric Units). EMISSION FACTORS FOR ASPHALT ROOFING^a

^a Factors represent uncontrolled emissions unless otherwise noted. Emission factors in kg/Mg of shingles produced unless noted. SCC = Source Classification Code. ND = no data. ESP = electrostatic precipitator. HEAF = high-energy air filter.

^b Total organic compounds as measured with an EPA Method 25A (or equivalent) sampling train.

^c Reference 10. Saturant blow of 1.5 hours. Expressed as kg/Mg of asphalt processed.

^d Reference 10. Coating blow of 4.5 hours. Expressed as kg/Mg of asphalt processed.

^e References 6-7.

^f Reference 6.

^g Reference 7.

^h Reference 9.

^j Reference 8.

^k Reference 3. Emission factors in kg/Mg of saturated felt produced.

Process	тось	EMISSION FACTOR RATING	со	EMISSION FACTOR RATING
Asphalt blowing: saturant asphalt ^c (SCC 3-05-001-01)	1.3	E	ND	
Asphalt blowing: coating asphalt ^d (SCC 3-05-001-02)	3.4	E	ND	
Asphalt blowing: saturant asphalt with afterburner ^d (SCC 3-05-001-01)	0.0043 ·	D	ND	
Asphalt blowing: coating asphalt with afterburner ^d (SCC 3-05-001-02)	0.017	D	ND	
Shingle saturation: dip saturator, drying-in drum section, wet looper, and coater ^e (SCC 3-05-001-16)	0.091	D	ND	
Shingle saturation: dip saturator, drying-in drum section, wet looper, and coater with ESP ^f (SCC 3-05-001-16)	0.098	D	ND	
Shingle saturation: dip saturator, drying-in drum section, and coater ^g (SCC 3-05-001-17)	ND		0.0019	D.
Shingle saturation: dip saturator, drying-in drum section, and wet looper with HEAF ^h (SCC 3-05-001-18)	0.094	D	ND	
Shingle saturation: spray/dip saturator, drying-in drum section, wet looper, coater, and storage tanks ^j (SCC 3-05-001-19)	0.26	D	ND	
Shingle saturation: spray/dip saturator, drying-in drum section, wet looper, coater, and storage tanks with HEAF ^j (SCC 3-05-001-19)	0.32	D	ND	
Asphalt blowing ^k (SCC 3-05-001-10)	ND		0.27	E
Asphalt blowing with afterburner ^k (SCC 3-05-001-10)	ND		3.7	E

Table 11.2-4 (English Units). EMISSION FACTORS FOR ASPHALT ROOFING^a

^a Factors represent uncontrolled emissions unless otherwise noted. Emission factors in lb/ton of shingles produced unless noted. SCC = Source Classification Code. ND = no data. ESP = electrostatic precipitator. HEAF = high-energy air filter.

^b Total organic compounds as measured with an EPA Method 25A (or equivalent) sampling train.

^c Reference 10. Saturant blow of 1.5 hours. Expressed as lb/ton of asphalt processed.

^d Reference 10. Coating blow of 4.5 hours. Expressed as lb/ton of asphalt processed.

^e References 6-7.

^f Reference 6.

^g Reference 7.

- ^h Reference 9.
- ^j Reference 8.

^k Reference 3. Emission factors in lb/ton of saturated felt produced.

Mineral Products Industry

References For Section 11.2

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11.3 Brick And Structural Clay Product Manufacturing

11.3.1 General¹⁻²

The brick and structural clay products industry is made up primarily of facilities that manufacture structural brick from clay, shale, or a combination of the two. These facilities are classified under standard industrial classification (SIC) code 3251, brick and structural clay tile. Facilities that manufacture structural clay products, such as clay pipe, adobe brick, chimney pipe, flue liners, drain tiles, roofing tiles, and sewer tiles are classified under SIC code 3259, structural clay products, not elsewhere classified.

11.3.2 Process Description³⁻⁶

The manufacture of brick and structural clay products involves mining, grinding, screening and blending of the raw materials followed by forming, cutting or shaping, drying, firing, cooling, storage, and shipping of the final product. A typical brick manufacturing process is shown in Figure 11.3-1.

The raw materials used in the manufacture of brick and structural clay products include surface clays and shales, which are mined in open pits. The moisture content of the raw materials ranges from a low of about 3 percent at some plants to a high of about 15 percent at other plants. Some facilities have onsite mining operations, while others bring in raw material by truck or rail. The raw material is typically loaded by truck or front-end loader into a primary crusher for initial size reduction. The material is then conveyed to a grinding room, which houses several grinding mills and banks of screens that produce a fine material that is suitable for forming brick or other products. Types of grinding mills typically used include dry pan grinders, roller mills, and hammermills. From the grinding room, the material is conveyed to storage silos or piles, which typically are enclosed. The material is then either conveyed to the mill room for brick forming or conveyed to a storage area.

Most brick are formed by the stiff mud extrusion process, although brick are also formed using the soft mud and dry press processes (there may be no plants in the U.S. currently using the dry press process). A typical stiff mud extrusion line begins with a pug mill, which mixes the ground material with water and discharges the mixture into a vacuum chamber. Some facilities mix additives such as barium carbonate, which prevents sulfates from rising to the surface of the brick, with the raw material prior to extrusion. The moisture content of the material entering the vacuum chamber is typically between 14 and 18 percent. The vacuum chamber removes air from the material, which is then continuously augered or extruded through dies. The resulting continuous "column" is lubricated with oil or other lubricant to reduce friction during extrusion. If specified, various surface treatments, such as manganese dioxide, iron oxide, and iron chromite can be applied at this point. These treatments are used to add color or texture to the product. A wire-cutting machine is used to cut the column into individual bricks, and then the bricks are mechanically or hand set onto kiln cars. All structural tile and most brick are formed by this process. Prior to stacking, some facilities mechanically process the unfired bricks to create rounded imperfect edges that give the appearance of older worn brick.

The soft mud process is usually used with clay that is too wet for stiff mud extrusion. In a pug mill, the clay is mixed with water to a moisture content of 15 to 28 percent, and the bricks are formed in molds and are dried before being mechanically stacked onto kiln cars. In the dry press process, clay is mixed with a small amount of water and formed in steel molds by applying pressure of 500 to 1,500 pounds per square inch (3.43 to 10.28 megapascals).



Figure 11.3-1. Typical brick manufacturing process. (Source Classification Codes in parentheses.) Following forming and stacking, the brick-laden kiln cars enter a predryer or a holding area and are then loaded into the dryer. Dryers typically are heated to about 400°F (204°C) using waste heat from the cooling zone of the kiln. However, some plants heat dryers with gas or other fuels. Dryers may be in-line or totally separate from the kiln. From the dryer, the bricks enter the kiln. The most common type of kiln used for firing brick is the tunnel kiln, although some facilities operate downdraft periodic kilns or other types of kilns. A typical tunnel kiln ranges from about 340 feet (ft) (104 meters [m]) to 500 ft (152 m) in length and includes a preheat zone, a firing zone, and a cooling zone. The firing zone typically is maintained at a maximum temperature of about 2000°F (1090°C). During firing, small amounts of excess fuel are sometimes introduced to the kiln atmosphere, creating a reducing atmosphere that adds color to the surface of the bricks. This process is called flashing. After firing, the bricks enter the cooling zone, where they are cooled to near ambient temperatures before leaving the tunnel kiln. The bricks are then stored and shipped.

A periodic kiln is a permanent brick structure with a number of fireholes through which fuel enters the furnace. Hot gases from the fuel are first drawn up over the bricks, then down through them by underground flues, and then out of the kiln to the stack.

In all kilns, firing takes place in six steps: evaporation of free water, dehydration, oxidation, vitrification, flashing, and cooling. Natural gas is the fuel most commonly used for firing, followed by coal and sawdust. Some plants have fuel oil available as a backup fuel. Most natural gas-fired plants that have a backup fuel use vaporized propane as the backup fuel. For most types of brick, the entire drying, firing, and cooling process takes between 20 and 50 hours.

Flashing is used to impart color to bricks by adding uncombusted fuel (other materials such as zinc, used tires, or used motor oil are also reportedly used) to the kiln to create a reducing atmosphere. Typically, flashing takes place in a "flashing zone" that follows the firing zone, and the bricks are rapidly cooled following flashing. In tunnel kilns, the uncombusted fuel or other material typically is drawn into the firing zone of the kiln and is burned.

11.3.3 Emissions And Controls^{3,7-11,22,24,29-30}

Emissions from brick manufacturing facilities include particulate matter (PM), PM less than or equal to 10 microns in aerodynamic diameter (PM-10), PM less than or equal to 2.5 microns in aerodynamic diameter (PM-2.5) sulfur dioxide (SO₂), sulfur trioxide (SO₃), nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO₂), metals, total organic compounds (TOC) (including methane, ethane, volatile organic compounds [VOC], and some hazardous air pollutants [HAP]), hydrochloric acid (HCl), and fluoride compounds. Factors that may affect emissions include raw material composition and moisture content, kiln fuel type, kiln operating parameters, and plant design. The pollutants emitted from the manufacture of other structural clay products are expected to be similar to the pollutants emitted from brick manufacturing, although emissions from the manufacture of glazed products may differ significantly.

The primary sources of PM, PM-10, and PM-2.5 emissions are the raw material grinding and screening operations and the kilns. Other sources of PM emissions include sawdust dryers used by plants with sawdust-fired kilns, coal crushing systems used by plants with coal-fired kilns, and fugitive dust sources such as paved roads, unpaved roads, and storage piles.

Combustion products, including SO_2 , NO_x , CO, and CO_2 , are emitted from fuel combustion in brick kilns and some brick dryers. Brick dryers that are heated with waste heat from the kiln cooling zone are not usually a source of combustion products because kilns are designed to prevent combustion gases from entering the cooling zone. Some brick dryers have supplemental gas burners that produce small amounts of NO_x , CO, and CO₂ emissions. These emissions are sensitive to the condition of the burners. The primary source of SO_2 emissions from most brick kilns is the raw material, which sometimes contain sulfur compounds. Some facilities use raw material with a high sulfur content, and have higher SO_2 emissions than facilities that use low-sulfur raw material. In addition, some facilities use additives that contain sulfates, and these additives may contribute to SO_2 emissions. Data are available that indicate that sulfur contents of surface soils are highly variable, and it is likely that sulfur contents of brick raw materials are also highly variable.

Organic compounds, including methane, ethane, VOC, and some HAP, are emitted from both brick dryers and kilns. These compounds also are emitted from sawdust dryers used by facilities that fire sawdust as the primary kiln fuel. Organic compound emissions from brick dryers may include contributions from the following sources: (1) petroleum-based or other products in those plants that use petroleum-based or other lubricants in extrusion, (2) light hydrocarbons within the raw material that vaporize at the temperatures encountered in the dryer, and (3) incomplete fuel combustion in dryers that use supplemental burners in addition to waste heat from the kiln cooling zone. Organic compound emissions from kilns are the result of volatilization of organic matter contained in the raw material and kiln fuel.

Hydrogen fluoride (HF) and other fluoride compounds are emitted from kilns as a result of the release of the fluorine compounds contained in the raw material. Fluorine typically is present in brick raw materials in the range of 0.01 to 0.06 percent. As the green bricks reach temperatures of 930° to 1110° F, $(500^{\circ} \text{ to } 600^{\circ}$ C), the fluorine in the raw material forms HF and other fluorine compounds. Much of the fluorine is released as HF. Because fluorine content in clays and shales is highly variable, emissions of HF and other fluoride compounds vary considerably depending on the raw material used.

A variety of control systems may be used to reduce PM emissions from brick manufacturing operations. Grinding and screening operations are sometimes controlled by fabric filtration systems, although many facilities process raw material with a relatively high moisture content (greater than 10 percent) and do not use add-on control systems. Most tunnel kilns are not equipped with control devices, although fabric filters or wet scrubbers are sometimes used for PM removal. Particulate matter emissions from fugitive sources such as paved roads, unpaved roads, and storage piles can be controlled using wet suppression techniques.

Gaseous emissions from brick dryers and kilns typically are not controlled using add-on control devices. However, dry scrubbers that use limestone as a sorption medium may be used to control HF emissions; control efficiencies of 95 percent or higher have been reported at one plant operating this type of scrubber. Also, wet scrubbers are used at one facility. These scrubbers, which use a soda ash and water solution as the scrubbing liquid, provide effective control of HF and SO₂ emissions. Test data show that the only high-efficiency packed tower wet scrubber operating in the U.S. (at brick plants) achieves control efficiencies greater than 99 percent for SO₂ and total fluorides. A unique "medium-efficiency" wet scrubber operating at the same plant has demonstrated an 82 percent SO₂ control efficiency.

Process controls are also an effective means of controlling kiln emissions. For example, facilities with coal-fired kilns typically use a low-sulfur, low-ash coal to minimize SO_2 and PM emissions. In addition, research is being performed on the use of additives (such as lime) to reduce HF and SO_2 emissions.

Table 11.3-1 presents emission factors for filterable PM, filterable PM-10, condensible inorganic PM, and condensible organic PM emissions from brick and structural clay product manufacturing operations. Two emission factors for uncontrolled grinding and screening operations are presented; one for operations processing relatively dry material (about 4 percent moisture) and the other for operations processing wet material (about 13 percent moisture). Table 11.3-2 presents total PM, total PM-10, and total PM-2.5 emission factors for brick and structural clay product manufacturing. Table 11.3-3 presents emission factors

for SO₂, SO₃, NO_x, CO, and CO₂ emissions from brick dryers, kilns (fired with natural gas, coal, and sawdust), and from a combined source--sawdust-fired kiln and sawdust dryer. To estimate emissions of NO_x, and CO from fuel oil-fired kilns, refer to the AP-42 section addressing oil combustion. Table 11.3-4 presents emission factors for HF, total fluorides, and HCl emissions from brick kilns and from a combined source--sawdust-fired kilns and sawdust drying. Table 11.3-5 presents emission factors for TOC as propane, methane, and VOC from brick dryers, kilns, and from a combined source--sawdust-fired kilns and sawdust drying. Tables 11.3-6 and 11.3-7 present emission factors for speciated organic compounds and metals, respectively. Table 11.3-8 presents particle size distribution data for sawdust- and coal-fired kilns. Although many of the emission factors presented in the tables are assigned lower ratings than emission factors in previous editions of AP-42, the new factors are based on higher quality data than the old factors.

	Filterable PM ^b					Condensible PM ^c				
Source	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	PM-2.5	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Primary crusher with fabric filter ^d (SCC 3-05-003-40)	ND	NA	0.00059	Ε	ND	NA	NA	NA	NA	NA
Grinding and screening operations (SCC 3-05-003-02)										
processing wet material ^f	0.025	E	0.0023	Е	ND	NA	NA	NA	NA	NA
processing dry material ^e	8.5	E	0.53	Е	ND	NA	NA	NA	NA	NA
with fabric filter ^g	0.0062	E	0.0032	Е	ND	NA	NA	NA	NA	NA
Extrusion line with fabric filter ^h (SCC 3-05-003-42)	ND	NA	0.0036	E	ND	NA	NA	NA	NA	NA
Brick dryer (SCC 3-05-003-50, -51)	0.077 ^j	E	ND	NA	ND	NA	0.11 ^k	E	ND	NA
Natural gas-fired kiln (SCC 3-05-003-11)	0.37 ^m	С	0.28 ⁿ	Е	ND	NA	0.48 ^p	D	0.11 ^q	D
Coal-fired kiln (SCC 3-05-003-13)										
uncontrolled	1.2 ^r	Α	0.76 ^s	С	0.28 ^t	D	0.48 ^p	D	0.11 ^q	D
with fabric filter	0.043 ^v	E	ND	NA	ND	NA	0.48 ^u	D	0.11 ^q	D
Sawdust-fired kiln (SCC 3-05-003-10)	0.34 ^w	D	0.26 ^x	D	0.16 ^x	D	0.48 ^p	D	0.11 ^q	D
Sawdust-fired kiln and sawdust dryer ^y (SCC 3-05-003-61)	1.3	Е	0.25	Е	ND	NA	0.013	Е	0.043	Е
Natural gas-fired kiln firing structural clay tile ² (SCC 3-05-003-70)	1.0	E	ND	NA	ND	NA	ND	NA	ND	NA

Table 11.3-1. PARTICULATE MATTER EMISSION FACTORS FOR BRICK MANUFACTURING OPERATIONS^a

^a Emission factor units are lb of pollutant per ton of fired bricks produced unless noted. Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data. NA = not applicable. To convert from lb/ton to kg/Mg, multiply by 0.5. Total PM can be calculated as the sum of filterable PM and condensible inorganic and organic PM. Total PM-10 can be calculated as the sum of filterable PM. Total PM-2.5 can be calculated as the sum of filterable PM-2.5 and condensible inorganic and organic PM.
 ^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

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- ^c Condensible PM is that PM collected in the impinger portion of an EPA Method 5 (or equivalent) sampling train or by EPA Method 202.
- ^d Reference 29.
- ^e Reference 8. Emission factor units are lb of pollutant per ton of raw material processed. Grinding and screening operations are typically housed in large buildings that can be fully or partially enclosed. Factor is based on measurements at the inlet to a fabric filter and does not take into account the effect of the building enclosure. Based on a raw material moisture content of 4 percent.
- ^f Reference 11. Emission factor units are lb of pollutant per ton of raw material processed. Based on a raw material moisture content of 13 percent. Grinding and screening operations are typically housed in large buildings that can be fully or partially enclosed.
- ^g References 8-9. Emission factor units are lb of pollutant per ton of raw material processed. Grinding and screening operations are typically housed in large buildings that can be fully or partially enclosed. Average raw material moisture content of 6.5 percent.
- ^h Reference 29. Extrusion line with several conveyor drop points processing material with a 5-9 percent moisture content. This emission factor is not applicable to typical extrusion lines.
- ^j Reference 21,36-37.
- ^k Reference 21.
- ^m References 8,12,15,22,25-26,29-30,32-34,36-37. Includes data from a kiln controlled with a dry scrubber.
- ⁿ Reference 25.
- ^p References 8-9,11,21,25,29-30,33-34.
- ^q References 8-9,11,25,29-30.
- ^r References 9,13-14,17-18,21.
- ^s References 9,13-14,17-18,21.
- ^t Reference 21.
- ^u Fabric filter is not expected to control condensible PM emissions. Therefore, the uncontrolled condensible PM emission factors are used.
- ^v Reference 19.
- ^w References 11,23.
- ^x References 11,20,23.
- ^y Reference 11. Sawdust dryer heated with the exhaust stream from a sawdust-fired kiln.
- ^z References 27-28.

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	Total Di di					
			10	tal PM ^o		
		EMISSION		EMISSION		EMISSION
		FACTOR	ł	FACTOR		FACTOR
Source	PM	RATING	PM-10	RATING	PM-2.5	RATING
Primary crusher with fabric filter (SCC 3-05-003-40)	ND	NA	0.00059	Е	ND	NA
Grinding and screening operations (SCC 3-05-003-02)						
processing dry material ^c	8.5	Е	0.53	Е	ND	NA
processing wet material ^d	0.025	Е	0.0023	Е	ND	NA
with fabric filter ^e	0.0062	Е	0.0032	Е	ND	NA
Extrusion line with fabric filter ^f (SCC 3-05-003-42)	ND	NA	0.0036	Е	ND	NA
Natural gas-fired kiln (SCC 3-05-003-11)	0.96	D	0. 87	D	ND	NA
Coal-fired kiln (SCC 3-05-003-13)						
uncontrolled	1.8	В	1.4	С	0.87	D
with fabric filter	0.63	Е	ND	NA	ND	NA
Sawdust-fired kiln (SCC 3-05-003-10)	0.93	D	0. 8 5	D	0.75	D
Sawdust-fired kiln and sawdust dryer ^g (SCC 3-05-003-61)	1.4	Е	0.31	E	ND	NA

Table 11.3-2. EMISSION FACTORS FOR TOTAL PM, TOTAL PM-10, AND TOTAL PM-2.5 FROM BRICK MANUFACTURING OPERATIONS^a

^a Emission factor units are lb of pollutant per ton of fired bricks produced unless noted. Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data. NA = not applicable. To convert from lb/ton to kg/Mg, multiply by 0.5.

^b Total PM emission factors are the sum of filterable PM and condensible inorganic and organic PM emission factors from Table 11.3-1. Total PM-10 emission factors are the sum of filterable PM-10 and condensible inorganic and organic PM emission factors from Table 11.3-1. Total PM-2.5 emission factors are the sum of filterable PM-2.5 and condensible inorganic and organic PM emission factors from Table 11.3-1.

^c Emission factor units are lb of pollutant per ton of raw material processed. Grinding and screening operations are typically housed in large buildings that can be fully or partially enclosed. Factor is based on measurements at the inlet to a fabric filter and does not take into account the effect of the building enclosure. Based on a raw material moisture content of 4 percent.

^d Emission factor units are lb of pollutant per ton of raw material processed. Based on a raw material moisture content of 13 percent. Grinding and screening operations are typically housed in large buildings that can be fully or partially enclosed.

^e Emission factor units are lb of pollutant per ton of raw material processed. Grinding and screening operations are typically housed in large buildings that can be fully or partially enclosed.

^f This emission factor is not applicable to typical extrusion lines. Extrusion line with several conveyor drop points processing material with a 5-9 percent moisture content.

^g Sawdust dryer heated with the exhaust stream from a sawdust-fired kiln.

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Table 11.3-3. EMISSION FACTORS FOR BRICK MANUFACTURING OPERATIONS^a

Source	SO2 ^b	EMISSION FACTOR RATING	SO3	EMISSION FACTOR RATING	NO _x	EMISSION FACTOR RATING	со	EMISSION FACTOR RATING	CO ₂	EMISSION FACTOR RATING
Brick dryer with supplemental gas burner ^c (SCC 3-05-003-51)	NA	NA	NA	NA	0.098 ^d	E	0.31 ^e	Е	71 ^f	E
Natural gas-fired kiln (SCC 3-05-003-11)	0.67 ^g	с	0.11 ^h	D	0.35 ^j	с	1.2 ^k	С	400 ^m	В
Natural gas-fired kiln firing high-sulfur material ⁿ (SCC 3-05-003-22)										
uncontrolled	5.1 ^p	D	ND	NA	0.35 ^j	с	1. 2^k	с	400 ^m	В
with medium-efficiency wet scrubber ^q	1.0 ^q	с	ND	NA	0.35 ^j	с	1.2 ^k	с	400 ^m	В
with high-efficiency packed-bed scrubber ^r	0.0049 ^r	с	ND	NA	0.35 ^j	с	1.2 ^k	с	400 ^m	В
Coal-fired kiln (SCC 3-05-003-13)	1.2 ^s	D	ND	NA	0.51 ^t	D	0.80 ^t	D	300 ^u	С
Sawdust-fired kiln (SCC 3-05-003-10)	0.67 ^g	с	0.11 ^h	D	0.37 ^v	E	1.6 ^x	D	490 ^x	D

^a Emission factor units are lb of pollutant per ton of fired bricks produced. Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data. NA = not applicable. To convert from lb/ton to kg/Mg, multiply by 0.5.

^b Because of highly variable percentages of sulfur in raw materials, SO_2 emissions can be more accurately estimated using mass balance procedures. Assuming that all of the sulfur in the raw material is released as SO_2 during firing, each lb of sulfur in the raw material will result in 2 lb of SO_2 emissions. The amount of SO_2 released may be reduced by contact with alkaline components of the raw materials or additives. To develop emission factors based on mass balance, the sulfur percentage should be presented as a percentage of dry raw material, because the emission factor is based on brick production (dry) rather than raw material (wet) use. Because SO_3 emissions are generally a small percentage of total sulfur oxide (SO_X) emissions, assume that all SO_x is SO_2 when performing mass balance calculations. For coal-fired kilns, the contribution of the coal to SO_2 emissions must also be accounted for when performing mass balance calculations.

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- ^c Brick dryer heated with waste heat from the cooling zone of the kiln and a supplemental gas burner or burners.
- ^d Reference 37.
- ^e References 8,36-37.
- ^f Reference 36-37.
- ^g References 12,15,22,25-26,32-33. Sulfur dioxide emissions are the result of pyrites or other sulfur compounds in the brick raw material. A mass balance on sulfur will provide a better estimate of emissions for individual facilities.
- ^h References 26,33,36-37.
- ^j References 8,12,15,25,29-30,32-34,36-37.
- ^k References 8,25,30,32,36-37.
- ^m References 8,12,15,22,25,27-30,32-34,36-37. A mass balance based on carbon burned will provide a better estimate of emissions for individual facilities.
- ⁿ Materials that have potentially high percentages of sulfur include fire clays, clays and shales mined in conjunction with coal mining activities, and other types of clay.
- P References 8,27-30, 36-37. Sulfur dioxide emissions are the result of pyrites or other sulfur compounds in the brick raw material. A mass balance on sulfur will provide a better estimate of emissions for individual facilities.
- ^q Reference 29. Medium-efficiency wet scrubber using a soda-ash/water solution (maintained at pH 7) as the scrubbing liquid. Scrubber is not expected to provide significant control of NO_x, CO, or CO₂. This emission factor was developed using data from a unique wet scrubber that is not a standard design air pollution control device.
- ^r Reference 30. High-efficiency packed bed scrubber with soda-ash/water solution circulated through the packing section. Scrubber is not expected to provide significant control of NO_x, CO, or CO₂.
- ^s References 10,16. Sulfur dioxide emissions are the result of sulfur in the coal and pyrites or other sulfur compounds in the brick raw material. A mass balance on sulfur will provide a better estimate of emissions for individual facilities.
- ^t References 9-10.
- ^u References 9-10,13-14,16-19,21.
- ^v Reference 11. Includes measurements following a sawdust dryer heated with the exhaust stream from a sawdust-fired kiln.
- ^x Reference 11,31,35. Includes measurements following a sawdust dryer heated with the exhaust stream from a sawdust-fired kiln.

Source	H₽₽	EMISSION FACTOR RATING	Total fluorides ^c	EMISSION FACTOR RATING	HCld	EMISSION FACTOR RATING
Sawdust- or natural gas-fired tunnel kiln (SCC 3-05-003-10,-11)						
uncontrolled	0.37 ^e	С	0.59 ^f	Е	0.17 ^g	D
with dry scrubber ^h	ND	NA	0.028	с	ND	NA
with medium-efficiency wet scrubber ^j	ND	NA	0.18	с	ND	NA
with high-efficiency packed-bed scrubber ^k	ND	NA	0.0013	С	ND	NA
Coal-fired tunnel kiln ^m (SCC 3-05-003-13)	0.17	D	ND	NA	ND	NA
Sawdust-fired kiln and sawdust dryer ⁿ (SCC 3-05-003-61)	0.18	Е	ND	NA	ND	NA

Table 11.3-4. EMISSION FACTORS FOR HYDROGEN FLUORIDE, TOTAL FLUORIDES, AND HYDROGEN CHLORIDE FROM BRICK MANUFACTURING OPERATIONS^a

- ^a Emission factor units are lb of pollutant per ton of fired product. Factors represent uncontrolled emissions unless noted. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data. NA = not applicable.
- ^b Hydrogen fluoride measured using an EPA Method 26A or equivalent sampling train.
- ^c Total fluorides measured using an EPA Method 13B or equivalent sampling train.
- ^d Hydrogen chloride measured using an EPA Method 26A or equivalent sampling train.
- ^e References 8,11,26-27,32,34. Factor includes data from kilns firing structural clay tile. Data from kilns firing natural gas and sawdust are averaged together because fuel type (except for coal) does not appear to affect HF emissions. However, the raw material fluoride content does effect HF emissions. A mass balance on fluoride will provide a better estimate of emissions for individual facilities. Assuming that all of the fluorine in the raw material is released as HF, each lb of fluorine will result in 1.05 lb of HF emissions.
- ^f Reference 26. Factor is 1.6 times the HF factor.
- ^g References 8,26.
- ^h References 22,33-34. Kiln firing material with a high fluorine content. Dry scrubber using limestone as a sorption medium.
- ^j Reference 29. Medium-efficiency wet scrubber using a soda-ash/water solution (maintained at pH 7) as the scrubbing liquid. The design of this scrubber is not typical. Kiln firing material with a high fluorine content.
- ^k Reference 30. High-efficiency packed bed scrubber with soda-ash/water solution circulated through the packing section. Kiln firing material with a high fluorine content (uncontrolled emission factor of 2.1 lb/ton).
- ^m References 9,26.
- ⁿ Reference 11. Sawdust dryer heated with the exhaust stream from a sawdust-fired kiln.

Source	тось	EMISSION FACTOR RATING	Methane	EMISSION FACTOR RATING	VOC ^c	EMISSION FACTOR RATING
Brick dryer ^d (SCC 3-05-003-50)	0.05 ^e	Е	0.02 ^f	Е	0.03	Е
Brick dryer w/supplemental gas burner (SCC 3-05-003-51)	0.14 ^g	Е	0.11 ^h	Е	0.03	Е
Brick kiln ^j (SCC 3-05-003-10,-11,-13)	0.062 ^k	С	0.037 ^m	Е	0.024	D
Sawdust-fired kiln and sawdust dryer ⁿ (SCC 3-05-003-61)	0.18	Е	ND	NA	0.18	Е

Table 11.3-5. EMISSION FACTORS FOR TOC, METHANE, AND VOC FROM BRICK MANUFACTURING OPERATIONS^a

- ^a Emission factor units are lb of pollutant per ton of fired product. Factors represent uncontrolled emissions unless noted. To convert from lb/ton to kg/Mg, multiply by 0.5. SCC = Source Classification Code. ND = no data. ND = not applicable.
- ^b Total organic compounds reported "as propane"; measured using EPA Method 25A, unless noted.
- ^c VOC as propane; calculated as the difference in the TOC and methane emission factors for this source. If no methane factor is available, VOC emissions are estimated using the TOC emission factor. In addition, emissions of the non-reactive compounds shown in Table 11.3-6 (brick kiln = 0.00094 lb/ton) are subtracted from the TOC factors to calculate VOC.
- ^d Brick dryer heated with waste heat from the kiln cooling zone.
- ^e References 9-10.
- ^f Reference 9. Methane value includes methane and ethane emissions. Most of these emissions are believed to be methane.
- ^g References 8,37.
- ^h Factor is estimated by assuming that VOC emissions from dryers with and without supplemental burners are equal. The VOC factor is subtracted from the TOC factor to estimate methane emissions.
- ^j Includes natural gas-, coal-, and sawdust-fired tunnel kilns.
- ^k References 8-11,25,32,36-37. Data from kilns firing natural gas, coal, and sawdust are averaged together because the data indicate that the fuel type does not effect TOC emissions.
- ^m References 8-9,25. Data from kilns firing natural gas, coal, and sawdust are averaged together because the data indicate that the fuel type does not effect methane emissions.
- ⁿ Reference 11. Sawdust dryer heated with the exhaust stream from a sawdust-fired kiln.

Table 11.3-6. EMISSION FACTORS FOR ORGANIC POLLUTANT EMISSIONS FROM BRICK MANUFACTURING OPERATIONS^a

	Pollutant		Enviroine Enotor	
Source	CASRN	Name	lb/ton	Ref. No.
Coal-fired kiln	75-34-3	1,1-dichloroethane	5.0x10 ⁻⁶	9
(SCC 3-05-003-13)	71-55-6	1,1,1-trichloroethane ^b *	BDL (1.7x10 ⁻⁵)	9
	106-46-7	1,4-dichlorobenzene	3.2x10 ⁻⁶	9
	78-93-3	2-butanone	2.5x10 ⁻⁴	9
	591-78-6	2-hexanone ^b	BDL (9.4x10 ⁻⁷)	9
	91-57-6	2-methylnaphthalene	1.7x10 ⁻⁶	9
	95-48-7	2-methylphenol ^b	BDL (2.2x10 ⁻⁶)	9
	67-64-1	Acetone*	6.8x10 ⁻⁴	9
	71-43-2	Benzene	2.9x10 ⁻⁴	9
	65-85-0	Benzoic acid	2.5x10 ⁻⁴	9
	117-81-7	Bis(2-ethylhexy)phthalate	7.3x10 ⁻⁵	9
	74-83-9	Bromomethane	2.4x10 ⁻⁵	9
	85-68-7	Butylbenzylphthalate	1.2x10 ⁻⁶	9
	75-15-0	Carbon disulfide	2.3x10 ⁻⁶	9
	56-23-5	Carbon tetrachloride ^b	BDL (1.0x10 ⁻⁷)	9
	108-90-7	Chlorobenzene	2.1x10 ⁻⁵	9
	75-00-3	Chloroethane	1.1x10 ⁻⁵	9
	67-66-3	Chloroform ^b	BDL (1.0x10 ⁻⁷)	9
	74-87-3	Chloromethane	1.1x10 ⁻⁴	9
	132-64-9	Dibenzofuran ^c	3.6x10 ⁻⁷	9
		Di-n-octylphthalate	1.2x10 ⁻⁵	9
	84-66-2	Diethylphthalate	1.4x10 ⁻⁶	9
	131-11-3	Dimethylphthalate ^b	BDL (7.8x10 ⁻⁷)	9
	100-41-4	Ethylbenzene	2.1x10 ⁻⁵	9
	78-59-1	Isophorone	3.0x10 ⁻⁵	9
	1330-20-7	M-/p-xylene	1.3x10 ⁻⁴	9
	75-09-2	Methylene chloride*	8.0x10 ⁻⁷	9
	91-20-3	Naphthalene	6.9x10 ⁻⁶	9
	95-47-6	O-xylene	4.7x10 ⁻⁵	9
	108-95-2	Phenol	3.5x10 ⁻⁵	9
	100-42-5	Styrene ^b	BDL (1.0x10 ⁻⁷)	9
	127-18-4	Tetrachloroethane ^b	BDL (1.0x10 ⁻⁷)	9
	71-55-6	Trichloroethane ^b *	BDL (1.0x10 ⁻⁷)	9
	108-88-3	Toluene	2.5x10 ⁻⁴	9
	108-05-4	Vinyl acetate ^b	BDL (1.0x10 ⁻⁷)	9
	75-69-4	Trichlorofluoromethane*	1.4x10 ⁻⁵	9

EMISSION FACTOR RATING: E

		Pollutant		
Source	CASRN	Name	Emission Factor, lb/ton	Ref. No.
Natural gas-fired kiln	71-55-6	1,1,1-Trichloroethane*	4.7x10 ⁻⁶	8
(SCC 3-05-003-11)	106-46-7	1,4-dichlorobenzene	4.8x10 ⁻⁵	8
	91-57-6	2-methylnaphthalene	5.7x10 ⁻⁵	8
	78-93-3	2-butanone	0.00022	8
	591-78- 6	2-Hexanone	8.5x10 ⁻⁵	8
	67-64-1	Acetone*	0.0017	8
	71-43-2	Benzene	0.0029	8
	117-81-7	Bis(2-ethylhexy)phthalate	0.0020	8
	85-68-7	Butylbenzylphthalate	1.8x10 ⁻⁵	8
	75-15-0	Carbon disulfide	4.3x10 ⁻⁵	8
	7782-50-5	Chlorine	0.0013	8
	75-00-3	Chloroethane	0.00057	8
	74-87-3	Chloromethane	0.00067	8
	84-74-2	Di-n-butylphthalate	0.00014	8
	84-66-2	Diethylphthalate	0.00024	8
	100-41-4	Ethylbenzene	4.4x10 ⁻⁵	8
	1330-20-7	M-/p-Xylene	6.7x10 ⁻⁵	8
	74-88-4	Iodomethane	9.3x10 ⁻⁵	8
	91-20-3	Naphthalene	6.5x10 ⁻⁵	8
	95-47-6	o-Xylene	5.8x10 ⁻⁵	8
	108-95-2	Phenol	8.6x10 ⁻⁵	8
	100-42-5	Styrene	2.0x10 ⁻⁵	8
	127-18-4	Tetrachloroethene	2.8x10 ⁻⁶	8
	108-88-3	Toluene	0.00016	8
Sawdust-fired kiln	71-55-6	1,1,1-trichloroethane ^b *	BDL (3.0x10 ⁻⁷)	11
(SCC 3-05-003-10)	78-93-3	2-butanone ^b	BDL (6.6x10 ⁻⁶)	11
	591-78-6	2-hexanone ^b	BDL (3.0x10 ⁻⁷)	11
	95-48-7	2-methylphenol ^b	BDL (2.0x10 ⁻⁹)	11
	67-64-1	Acetone*	3.9x10 ⁻⁴	11
	107-13-1	Acrylonitrile ^c	1.5x10 ⁻⁵	11
	71-43-2	Benzene	5.2x10 ⁻⁴	11
	117-81-7	Bis(2-ethylhexy)phthalate	2.9x10 ⁻⁵	11
	74-83-9	Bromomethane	5.0x10 ⁻⁵	11
	75-15-0	Carbon disulfide	1.6x10 ⁻⁵	11
	56-23-5	Carbon tetrachloride ^b	BDL (3.0x10 ⁻⁷)	11
	67-66-3	Chloroform ^b	BDL (3.0x10 ⁻⁷)	11
	74-87-3	Chloromethane	6.8x10 ⁻⁴	11
1	84-74-2	Di-n-butylphthalate ^c	6.1x10 ⁻⁶	11
	132-64-9	Dibenzofuran	1.5x10 ⁻⁵	11

Table 11.3-6 (cont.).

		Pollutant		
Source	CASRN	Name	Emission Factor, lb/ton	Ref. No.
Sawdust-fired kiln	84-74-2	Dimethylphthalate ^c	1.0x10 ⁻⁵	11
(SCC 3-05-003-10)	100-41-4	Ethylbenzene	8.5x10 ⁻⁶	11
	74-88-4	Iodomethane	2.0x10 ⁻⁴	11
	1330-20-7	M-/p-xylene	2.9x10 ⁻⁵	11
	75-09-2	Methylene chloride*	7.5x10 ⁻⁶	11
	91-20-3	Naphthalene ^c	3.4x10 ⁻⁴	11
	95-47-6	O-xylene ^c	3.8x10 ⁻⁶	11
	108-95-2	Phenol	7.2x10 ⁻⁵	11
	100-42-5	Styrene ^b	BDL (4.4x10 ⁻⁷)	11
	127-18-4	Tetrachloroethane ^b	BDL (3.0x10 ⁻⁷)	11
	108-88-3	Toluene	1.1x10 ⁻⁴	11
	71-55-6	Trichloroethane ^b *	BDL (3.0x10 ⁻⁷)	11
	75-69-4	Trichlorofluoromethane*	5.8x10 ⁻⁶	11
	108-05-4	Vinyl acetate ^b	BDL (3.0x10 ⁻⁷)	11
Sawdust-fired kiln	71-55-6	1,1,1-trichloroethaneb*	BDL (5.2x10 ⁻⁷)	11
and sawdust dryer ^a (SCC 3-05-003-61)	78-93-3	2-butanone	2.2x10 ⁻⁴	11
	591-78-6	2-hexanone ^b	BDL (3.8x10 ⁻⁷)	11
	95-48-7	2-methylphenol ^b	BDL (2.4x10 ⁻⁹)	11
	67-64-1	Acetone*	0.0010	11
	107-13-1	Acrylonitrile	1.9x10 ⁻⁵	11
	71-43-2	Benzene	5.6x10 ⁻⁴	11
	117-81-7	Bis(2-ethylhexy)phthalate	1.4x10 ⁻⁴	11
	74-83-9	Bromomethane	4.4x10 ⁻⁵	11
	75-15-0	Carbon disulfide	1.8x10 ⁻⁵	11
	56-23-5	Carbon tetrachloride ^b	BDL (3.8x10 ⁻⁷)	11
	67-66-3	Chloroform ^b	BDL (3.8x10 ⁻⁷)	11
	74-87-3	Chloromethane	0.0014	11
	84-74-2	Di-n-butylphthalate	1.6x10 ⁻⁵	11
	132-64-9	Dibenzofuran ^b	BDL (2.4x10 ⁻⁹)	11
	131-11-3	Dimethylphthalate ^b	BDL (2.4x10 ⁻⁹)	11
	100-41-4	Ethylbenzene	1.0x10 ⁻⁵	11
	74-88-4	Iodomethane	2.4x10 ⁻⁴	11
	1330-20-7	M-/p-xylene	2.9x10 ⁻⁵	11
	75-09-2	Methylene chloride*	6.2x10 ⁻⁵	11
	91-20-3	Naphthalene ^b	BDL (2.4x10 ⁻⁹)	11
	95-47-6	O-xylene	7.3x10 ⁻⁶	11
	108-95-2	Phenol	1.0x10 ⁻⁴	11
	100-42-5	Styrene ^b	BDL (4.2x10 ⁻⁶)	11
	127-18-4	Tetrachloroethane ^b	BDL (3.8x10 ⁻⁷)	11

Table 11.3-6 (cont.).

Table 11.3-6 (cont.).

		Pollutant	Emission Easter	
Source	CASRN	Name	lb/ton	Ref. No.
Sawdust-fired kiln and	108-88-3	Toluene	4.3x10 ⁻⁴	11
(SCC 3-05-003-61)	71-55-6	Trichloroethane ^b *	BDL (3.8x10 ⁻⁷)	11
	75-69-4	Trichlorofluoromethane*	1.0x10 ⁻⁶	11
	108-05-4	Vinyl acetate	1.9x10 ⁻⁷	11

^a Emission factor units are lb of pollutant per ton of fired bricks produced. To convert from lb/ton to kg/Mg, multiply by 0.5. CASRN = Chemical Abstracts Service Registry Number. * = Non-reactive compound as designated in 40 CFR 51.100(s), July 1, 1995. BDL = concentration was below the method detection limit.

^b The emission factor for this pollutant is shown in parentheses and is based on the detection limit.

^c Emissions were below the detection limit during two of three test runs. Emission factor is estimated as the average of the single measured quantity and one-half of the detection limit for the two nondetect runs.

^d These emission factors are based on data from an atypical facility.

^e Sawdust dryer heated with the exhaust stream from a sawdust-fired kiln.

			EMISSION	
		Emission Factor,	FACTOR	Reference
Source	Pollutant	lb/ton	RATING	Nos.
Kiln ^b (SCC 3-05-003-10,-11,-13)	Antimony	2.7x10 ⁻⁵	D	8-9,11,25
	Cadmium	1.5x10 ⁻⁵	D	8-9,11,25
	Chromium	5.1x10 ⁻⁵	D	9,11,25
	Cobalt	2.1x10 ⁻⁶	Е	25
	Lead	1.5x10 ⁻⁴	D	8-9,11,25
	Nickel	7.2x10 ⁻⁵	D	9,11,25
	Selenium	2.3x10 ⁻⁴	D	8-9,11,25
Coal-fired kiln (SCC 3-05-003-13)	Arsenic	1.3x10 ⁻⁴	Е	9
	Beryllium	1.6x10 ⁻⁵	Е	9
	Manganese	2.9x10 ⁻⁴	D	8-9,25
	Mercury	9.6x10 ⁻⁵	Е	9
	Phosphorus	9.8x10 ⁻⁴	E	9,11
Natural gas-fired kiln (SCC 3-05-003-11)	Arsenic	3.1x10 ⁻⁵	D	8,11,25
	Beryllium	4.2x10 ⁻⁷	D	8,11,25
	Manganese	2.9x10 ⁻⁴	D	8-9,25
	Mercury	7.5x10 ⁻⁶	D	11,25
Sawdust-fired kiln (SCC 3-05-003-10)	Arsenic	3.1x10 ⁻⁵	D	8,11,25
	Beryllium	4.2x10 ⁻⁷	D	8,11,25
	Manganese	0.013 ^c	E	11
	Mercury	7.5x10 ⁻⁶	D	11,25
	Phosphorus	9.8x10 ⁻⁴	E	9,11
Sawdust-fired kiln and sawdust dryer ^d	Antimony	2.8x10 ⁻⁶	Е	11
(SCC 3-05-003-61)	Arsenic	2.1x10 ⁻⁵	Е	11
	Beryllium	3.1x10 ⁻⁷	Е	11
	Cadmium	2.2x10 ⁻⁵	E	11
	Chromium	4.8x10 ⁻⁵	Е	11
	Lead	1.2×10^{-4}	E	11
	Manganese	4.8x10 ⁻⁴	Е	11
	Mercury	1.1x10 ⁻⁵	Е	11
	Nickel	3.4x10 ⁻⁵	E	11
	Phosphorus	5.5x10 ⁻⁴	Е	11
	Selenium	4.7x10 ⁻⁵	E	11

Table 11.3-7. EMISSION FACTORS FOR METALS EMISSIONS FROM BRICK MANUFACTURING OPERATIONS^a

^a Emission factor units are lb of pollutant per ton of fired brick produced. Emission factors for individual facilities will vary based on the metal content of the raw material, metallic colorants used on the face of the bricks, metallic additives mixed into the bodies of the bricks, and the metal content of the fuels used for firing the kilns.

- ^b Coal-, natural gas-, or sawdust-fired tunnel kiln.
- ^c The facility uses a manganese surface treatment on the bricks. The manganese emission factor for coaland natural gas-fired kilns is a better estimate for sawdust-fired kilns firing bricks that do not have a manganese surface treatment. Conversely, this emission factor should be used to estimate manganese emissions from coal- or natural gas-fired kilns firing a product with manganese surface treatment.

^d Sawdust dryer heated with the exhaust stream from a sawdust-fired kiln.

Table 11.3.8. AVERAGE PARTICLE SIZE DISTRIBUTIONFOR FILTERABLE PM EMISSIONS FROM KILNS^a

Source	Aerodynamic Diameter, microns	Percent of Filterable PM Emissions Less Than or Equal to Stated Particle Size	Reference No.
Sawdust-fired kiln	10 ^b	75	11,20
	2.5	48	11,20
	1	44	11,20
Coal-fired kiln	10 ^b	63	9,21
	2.5	23	21
	1	9.8	21

- ^a Particle size distribution based on cascade impactor tests unless noted.
- ^b Based on cascade impactor particle size distribution and a comparison of PM-10 (measured using EPA Method 201A) and filterable PM (measured using EPA Method 5) emissions.

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11.4 Calcium Carbide Manufacturing

11.4.1 General

Calcium carbide (CaC_2) is manufactured by heating a lime and carbon mixture to 2000 to 2100°C (3632 to 3812°F) in an electric arc furnace. At those temperatures, the lime is reduced by carbon to calcium carbide and carbon monoxide (CO), according to the following reaction:

$$CaO + 3C \rightarrow CaC_2 + CO$$

Lime for the reaction is usually made by calcining limestone in a kiln at the plant site. The sources of carbon for the reaction are petroleum coke, metallurgical coke, and anthracite coal. Because impurities in the furnace charge remain in the calcium carbide product, the lime should contain no more than 0.5 percent each of magnesium oxide, aluminum oxide, and iron oxide, and 0.004 percent phosphorus. Also, the coke charge should be low in ash and sulfur. Analyses indicate that 0.2 to 1.0 percent ash and 5 to 6 percent sulfur are typical in petroleum coke. About 991 kilograms (kg) (2,185 pounds [lb]) of lime, 683 kg (1,506 lb) of coke, and 17 to 20 kg (37 to 44 lb) of electrode paste are required to produce 1 megagram (Mg) (2,205 lb) of calcium carbide.

The process for manufacturing calcium carbide is illustrated in Figure 11.4-1. Moisture is removed from coke in a coke dryer, while limestone is converted to lime in a lime kiln. Fines from coke drying and lime operations are removed and may be recycled. The two charge materials are then conveyed to an electric arc furnace, the primary piece of equipment used to produce calcium carbide. There are three basic types of electric arc furnaces: the open furnace, in which the CO burns to carbon dioxide (CO₂) when it contacts the air above the charge; the closed furnace, in which the gas is collected from the furnace and is either used as fuel for other processes or flared; and the semi-covered furnace, in which mix is fed around the electrode openings in the primary furnace cover resulting in mix seals. Electrode paste composed of coal tar pitch binder and anthracite coal is fed into a steel casing where it is baked by heat from the electric arc furnace before being introduced into the furnace. The baked electrode exits the steel casing just inside the furnace cover and is consumed in the calcium carbide production process. Molten calcium carbide is tapped continuously from the furnace into chills and is allowed to cool and solidify. Then, the solidified calcium carbide goes through primary crushing by jaw crushers, followed by secondary crushing and screening for size. To prevent explosion hazards from acetylene generated by the reaction of calcium carbide with ambient moisture, crushing and screening operations may be performed in either an air-swept environment before the calcium carbide has completely cooled, or in an inert atmosphere. The calcium carbide product is used primarily in generating acetylene and in desulfurizing iron.

11.4.2 Emissions And Controls

Emissions from calcium carbide manufacturing include particulate matter (PM), sulfur oxides (SO_x) , CO, CO₂, and hydrocarbons. Particulate matter is emitted from a variety of equipment and operations in the production of calcium carbide including the coke dryer, lime kiln, electric furnace, tap fume vents, furnace room vents, primary and secondary crushers, and conveying equipment. (Lime kiln emission factors are presented in Section 11.17). Particulate matter emitted from a process source such as an electric furnace is ducted to a PM control device, usually a fabric filter or wet scrubber. Fugitive PM from sources such as tapping operations, the furnace room, and conveyors is captured and sent to a PM control device. The composition of the PM varies according

D PM emissions
C Gaseous emissions



Figure 11.4-1. Process flow diagram for calcium carbide manufacturing. (SCC = Source Classification Code).

to the specific equipment or operation, but the primary components are calcium and carbon compounds, with significantly smaller amounts of magnesium compounds.

Sulfur oxides may be emitted both by the electric furnace from volatilization and oxidation of sulfur in the coke feed, and by the coke dryer and lime kiln from fuel combustion. These process sources are not controlled specifically for SO_x emissions. Carbon monoxide is a byproduct of calcium carbide production in the electric furnace. Carbon monoxide emissions to the atmosphere are usually negligible. In open furnaces, CO is oxidized to CO_2 , thus eliminating CO emissions. In closed furnaces, a portion of the generated CO is burned in the flames surrounding the furnace charge holes, and the remaining CO is either used as fuel for other processes or is flared. In semi-covered furnaces, the CO that is generated is either used as fuel for the lime kiln or other processes, or is flared.

The only potential source of hydrocarbon emissions from the manufacture of calcium carbide is the coal tar pitch binder in the furnace electrode paste. Since the maximum volatiles content in the electrode paste is about 18 percent, the electrode paste represents only a small potential source of hydrocarbon emissions. In closed furnaces, actual hydrocarbon emissions from the consumption of electrode paste typically are negligible because of high furnace operating temperature and flames surrounding the furnace charge holes. In open furnaces, hydrocarbon emissions are expected to be negligible because of high furnace operating temperatures and the presence of excess oxygen above the furnace. Hydrocarbon emissions from semi-covered furnaces are also expected to be negligible because of high furnace operating temperatures.

Tables 11.4-1 and 11.4-2 give controlled and uncontrolled emission factors in metric and English units, respectively, for various processes in the manufacture of calcium carbide. Controlled factors are based on test data and permitted emissions for operations with the fabric filters and wet scrubbers that are typically used to control PM emissions in calcium carbide manufacturing.

Table 11.4-1 (Metric Units). EMISSION FACTORS FOR CALCIUM CARBIDE MANUFACTURING^a

Process	Filterable PM ^b (kg/Mg feed)	Condensable Inorganic PM ^c (kg/Mg feed)	Sulfur Oxides (kg/Mg feed)	CO ₂ (kg/Mg feed)
Electric arc furnace main stack (SCC 3-05-004-01) ^d	13 ^e	ND	1.5 ^f	ND
Electric arc furnace main stack with fabric filter (SCC 3-05-004-01) ^d	0.32 ^g	0.37 ^g	ND	Neg ^h
Electric arc furnace main stack with scrubber (SCC 3-05-004-01) ^d	0.25 ^e	ND	ND	ND
Electric arc furnace and calcium carbide cooling conveyor with fabric filter (SCC 3-05-004) ^d	0.035 ^{j,k}	ND	NĎ	Neg ^m
Coke dryer (SCC 3-05-004-02)	1.0 ^f	ND	1.5 ^f	ND
Coke dryer with fabric filter (SCC 3-05-004-02)	0.13 ⁿ	ND	NA	ND
Furnace room vents (SCC 3-05-004-03)	13 ^f	ND	ND	ND
Furnace room vents with fabric filter (SCC 3-05-004-03)	0.07 ⁿ	ND	ND	ND
Tap fume vents with fabric filter (SCC 3-05-004-04)	0.07 ⁿ	ND	ND	ND
Primary and secondary crushing with fabric filter (SCC 3-05-004-05)	0.055 ⁿ	ND	NA	NA
Circular charging conveyor with fabric filter (SCC 3-05-004-06)	0.11 ⁿ	ND	NA	NA

EMISSION FACTOR RATING: E (except as noted)

^a Factors are for uncontrolled emissions, unless otherwise noted. Factors are kg/Mg of feed unless noted. Feed materials: electric furnace - coke and lime; coke dryer - coke; tap fume vent - coke and lime; furnace room vent - coke and lime; crusher - calcium carbide; charging conveyor - coke and lime. NA = not applicable. ND = no data. Neg = negligible. SCC = Source Classification Code. ^b Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Condensable PM is that collected in the impinger portion of a PM sampling train.

^d Emission factors applicable to open furnaces using petroleum coke.

^e Reference 4.

^f From previous AP-42 section; reference not specified. ^g References 8,13. EMISSION FACTOR RATING: C.

^h Reference 13.

^j Reference 12; emission factor in kg/Mg of calcium carbide produced.

- **k** EMISSION FACTOR RATING: D.
- ^m Reference 12.
- ⁿ Reference 1.

1/95

EMISSION FACTOR RATING:	E (except as noted)
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Process	Filterable PM ^b (lb/ton)	Condensable Inorganic PM ^c (lb/ton)	Sulfur Oxides (lb/ton)	CO ₂ (lb/ton)
Electric arc furnace main stack (SCC 3-05-004-01) ^d	26 ^e	ND	3.0 ^f	ND
Electric arc furnace main stack with fabric filter (SCC 3-05-004-01) ^d	0.63 ^g	0.73 ^g	ND	Neg ^h
Electric arc furnace main stack with scrubber (SCC 3-05-004-01) ^d	0.50 ^e	ND	ND	ND
Electric arc furnace and calcium carbide cooling conveyor with fabric filter (SCC 3-05-004) ^d	0.70 ^{j,k}	ND	ND	Neg ^m
Coke dryer (SCC 3-05-004-02)	2.0 ^f	ND	3.0 ^f	ND
Coke dryer with fabric filter (SCC 3-05-004-02)	0.26 ⁿ	ND	NA	ND
Furnace room vents (SCC 3-05-004-03)	26 ^f	ND	ND	ND
Furnace room vents with fabric filter (SCC 3-05-004-03)	0.14 ⁿ	ND	ND	ND
Tap fume vents with fabric filter (SCC 3-05-004-04)	0.14 ⁿ	ND	ND	ND
Primary and secondary crushing with fabric filter (SCC 3-05-004-05)	0.11 ⁿ	ND	NA	NA
Circular charging conveyor with fabric filter (SCC 3-05-004-06)	0.22 ⁿ	ND	NA	NA

^a Factors are for uncontrolled emissions, unless otherwise noted. Factors in lb/ton of feed unless noted. Feed materials: electric furnace - coke and lime; coke dryer - coke; tap fume vent - coke and lime; furnace room vent - coke and lime; crusher - calcium carbide; charging conveyor - coke and lime. NA = not applicable. ND = no data. Neg = negligible. SCC = SourceClassification Code.

^b Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Condensable PM is that collected in the impinger portion of a PM sampling train.

^d Emission factors applicable to open furnaces using petroleum coke.

^e Reference 4.

^f From previous AP-42 section; reference not specified. ^g References 8,13. EMISSION FACTOR RATING: C

^h Reference 13.

^j Reference 12; emission factor in kg/Mg of calcium carbide produced.

k EMISSION FACTOR RATING: D.

^m Reference 12.

11.4-5

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11.5 Refractory Manufacturing

11.5.1 Process Description¹⁻²

Refractories are materials that provide linings for high-temperature furnaces and other processing units. Refractories must be able to withstand physical wear, high temperatures (above $538^{\circ}C$ [1000°F]), and corrosion by chemical agents. There are two general classifications of refractories, clay and nonclay. The six-digit source classification code (SCC) for refractory manufacturing is 3-05-005. Clay refractories are produced from fireclay (hydrous silicates of aluminum) and alumina (57 to 87.5 percent). Other clay minerals used in the production of refractories include kaolin, bentonite, ball clay, and common clay. Nonclay refractories are produced from a composition of alumina (< 87.5 percent), mullite, chromite, magnesite, silica, silicon carbide, zircon, and other nonclays.

Refractories are produced in two basic forms, formed objects, and unformed granulated or plastic compositions. The preformed products are called bricks and shapes. These products are used to form the walls, arches, and floor tiles of various high-temperature process equipment. Unformed compositions include mortars, gunning mixes, castables (refractory concretes), ramming mixes, and plastics. These products are cured in place to form a monolithic, internal structure after application.

Refractory manufacturing involves four processes: raw material processing, forming, firing, and final processing. Figure 11.5-1 illustrates the refractory manufacturing process. Raw material processing consists of crushing and grinding raw materials, followed if necessary by size classification and raw materials calcining and drying. The processed raw material then may be dry-mixed with other minerals and chemical compounds, packaged, and shipped as product. All of these processes are not required for some refractory products.

Forming consists of mixing the raw materials and forming them into the desired shapes. This process frequently occurs under wet or moist conditions. Firing involves heating the refractory material to high temperatures in a periodic (batch) or continuous tunnel kiln to form the ceramic bond that gives the product its refractory properties. The final processing stage involves milling, grinding, and sandblasting of the finished product. This step keeps the product in correct shape and size after thermal expansion has occurred. For certain products, final processing may also include product impregnation with tar and pitch, and final packaging.

Two other types of refractory processes also warrant discussion. The first is production of fused products. This process involves using an electric arc furnace to melt the refractory raw materials, then pouring the melted materials into sand-forming molds. Another type of refractory process is ceramic fiber production. In this process, calcined kaolin is melted in an electric arc furnace. The molten clay is either fiberized in a blowchamber with a centrifuge device or is dropped into an air jet and immediately blown into fine strands. After the blowchamber, the ceramic fiber may then be conveyed to an oven for curing, which adds structural rigidity to the fibers. During the curing process, oils are used to lubricate both the fibers and the machinery used to handle and form the fibers. The production of ceramic fiber for refractory material is very similar to the production of mineral wool.



Figure 11.5-1. Refractory manufacturing process flow diagram.¹ (Source Classification Codes in parentheses.)

11.5.2 Emissions And Controls²⁻⁶

The primary pollutant of concern in refractory manufacturing is particulate matter (PM). Particulate matter emissions occur during the crushing, grinding, screening, calcining, and drying of the raw materials; the drying and firing of the unfired "green" refractory bricks, tar and pitch operations; and finishing of the refractories (grinding, milling, and sandblasting).

Emissions from crushing and grinding operations generally are controlled with fabric filters. Product recovery cyclones followed by wet scrubbers are used on calciners and dryers to control PM emissions from these sources. The primary sources of PM emissions are the refractory firing kilns and electric arc furnaces. Particulate matter emissions from kilns generally are not controlled. However, at least one refractory manufacturer currently uses a multiple-stage scrubber to control kiln emissions. Particulate matter emissions from electric arc furnaces generally are controlled by a baghouse. Particulate removal of 87 percent and fluoride removal of greater than 99 percent have been reported at one facility that uses an ionizing wet scrubber.

Pollutants emitted as a result of combustion in the calcining and kilning processes include sulfur dioxide (SO_2) , nitrogen oxides (NO_x) , carbon monoxide (CO), carbon dioxide (CO_2) , and volatile organic compounds (VOC). The emission of SO_x is also a function of the sulfur content of certain clays and the plaster added to refractory materials to induce brick setting. Fluoride emissions occur during the kilning process because of fluorides in the raw materials. Emission factors for filterable PM, PM-10, SO_2 , NO_x , and CO_2 emissions from rotary dryers and calciners processing fire clay are presented in Tables 11.5-1 and 11.5-2. Particle size distributions for filterable particulate emissions from rotary dryers and calciners processing fire clay are presented in Table 11.5-3.

Volatile organic compounds emitted from tar and pitch operations generally are controlled by incineration, when inorganic particulates are not significant. Based on the expected destruction of organic aerosols, a control efficiency in excess of 95 percent can be achieved using incinerators.

Chromium is used in several types of nonclay refractories, including chrome-magnesite, (chromite-magnesite), magnesia-chrome, and chrome-alumina. Chromium compounds are emitted from the ore crushing, grinding, material drying and storage, and brick firing and finishing processes used in producing these types of refractories. Tables 11.5-4 and 11.5-5 present emission factors for emissions of filterable PM, filterable PM-10, hexavalent chromium, and total chromium from the drying and firing of chromite-magnesite ore. The emission factors are presented in units of kilograms of pollutant emitted per megagram of chromite ore processed (kg/Mg CrO_3) (pounds per ton of chromite ore processed [lb/ton CrO_3]). Particle size distributions for the drying and firing of chromite-magnesite ore are summarized in Table 11.5-6.

A number of elements in trace concentrations including aluminum, beryllium, calcium, chromium, iron, lead, mercury, magnesium, manganese, nickel, titanium, vanadium, and zinc also are emitted in trace amounts by the drying, calcining, and firing operations of all types of refractory materials. However, data are inadequate to develop emission factors for these elements.

Emissions of PM from electric arc furnaces producing fused cast refractory material are controlled with baghouses. The efficiency of the fabric filters often exceeds 99.5 percent. Emissions of PM from the ceramic fiber process also are controlled with fabric filters, at an efficiency similar to that found in the fused cast refractory process. To control blowchamber emissions, a fabric filter is used to remove small pieces of fine threads formed in the fiberization stage. The efficiency of fabric filters in similar control devices exceeds 99 percent. Small particles of ceramic fiber are broken off or separated during the handling and forming of the fiber blankets in the curing oven. An oil is used in this process, and higher molecular weight organics may be emitted. However, these emissions generally are controlled with a fabric filter followed by incineration, at an expected overall efficiency in excess of 95 percent.

Table 11.5-1 (Metric Units).	EMISSION	FACTORS FOR	REFRACTORY
MANUFA	CTURING:	FIRE CLAY ^a	

				Filter	able ^b
Process	SO ₂	NO _x	CO ₂	РМ	PM-10
Rotary dryer ^c (SCC 3-05-005-01)	ND	ND	15	33	8.1
Rotary dryer with cyclone (SCC 3-05-005-01)	ND	ND	15	5.6	2.6
Rotary dryer with cyclone and wet scrubber ^c (SCC 3-05-005-01)	ND	ND	15	0.052	ND
Rotary calciner (SCC 3-05-005-06)	ND	ND	300°	62 ^d	14 ^e
Rotary calciner with multiclone (SCC 3-05-005-06)	ND	ND	300°	31 ^f	ND
Rotary calciner with multiclone and wet scrubber (SCC 3-05-005-06)	3.8 ^d	0.87 ^d	300 ^c	0.15 ^d	0.031 ^e

EMISSION FACTOR RATING: D

^a Factors represent uncontrolled emissions, unless noted. All emission factors in kg/Mg of raw material feed. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.

^c Reference 3.

^d References 4-5.

^e Reference 4.

^f Reference 5.

11.5-4

Table 11.5-2 (English Units). EMISSION FACTORS FOR REFRACTORY MANUFACTURING: FIRE CLAY^a

				Filter	able ^b
Process	SO ₂	NO _x	CO ₂	РМ	PM-10
Rotary dryer ^c (SCC 3-05-005-01)	ND	ND	30	65	16
Rotary dryer with cyclone ^c (SCC 3-05-005-01)	ND	ND	30	11	5.1
Rotary dryer with cyclone and wet scrubber ^c (SCC 3-05-005-01)	ND	ND	30	0.11	ND
Rotary calciner (SCC 3-05-005-06)	ND	ND	600°	120 ^d	30 ^e
Rotary calciner with multiclone (SCC 3-05-005-06)	ND	ND	600°	61 ^f	ND
Rotary calciner with multiclone and wet scrubber (SCC 3-05-005-06)	7.6 ^d	1.7 ^d	ND	0.30 ^d	0.062 ^e

EMISSION FACTOR RATING: D

^a Factors represent uncontrolled emissions, unless noted. All emission factors in lb/ton of raw material feed. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.

^c Reference 3.

^d References 4-5.

^e Reference 4.

^f Reference 5.

Table 11.5-3. PARTICLE SIZE DISTRIBUTIONS FOR REFRACTORY MANUFACTURING: FIRE CLAY^a

	Uncontrolled	Multiclone Controlled	Cyclone Controlled	Cyclone/Scrubber Controlled
Diameter (µm)	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter
Rotary Dryers (SCC 3-05-005-01) ^b		_	
2.5	2.5	ND	14	ND
6.0	10	ND	31	ND
10.0	24	ND	46	ND
15.0	37	ND	60	ND
20.0	51	ND	68	ND
Rotary Calciner	s (SCC 3-05-005-06	5)°		
1.0	3.1	13	ND	31
1.25	4.1	14	ND	43
2.5	6.9	23	ND	46
6.0	17	39	ND	55
10.0	34	50	ND	69
15.0	50	63	ND	81
20.0	62	81	ND	91

EMISSION FACTOR RATING: D

^a For filterable PM only. ND = no data. SCC = Source Classification Code.

^b Reference 3.

^c References 4-5 (uncontrolled). Reference 4 (multiclone-controlled). Reference 5 (cyclone/scrubber-controlled).

Table 11.5-4 (Metric Units). EMISSION FACTORS FOR REFRACTORY MANUFACTURING: CHROMITE-MAGNESITE ORE^a

	Filt	erable ^b	Chromium ^c		
Process	PM	PM-10	Hexavalent	Total	
Rotary dryer (SCC 3-05-005-08)	0.83	0.20	3.8x10 ⁻⁵	0.035	
Rotary dryer with cyclone and fabric filter (SCC 3-05-005-08)	0.15	ND	1.9x10 ⁻⁵	0.064	
Tunnel kiln (SCC 3-05-005-09)	0.41	0.34	0.0087	0.13	

EMISSION FACTOR RATING: D (except as noted)

^a Reference 6. Factors represent uncontrolled emissions. Factors for filterable PM are kg/Mg of material processed. Factors for chrominum are kg/Mg of chromite ore processed.
 SCC = Source Classification Code for chromium. ND = no data.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution and filterable PM emission factor.

° EMISSION FACTOR RATING: E.

Table 11.5-5 (English Units). EMISSION FACTORS FOR REFRACTORY MANUFACTURING: CHROMITE-MAGNESITE ORE^a

	Filte	erable ^b	Chromium ^c		
Process	PM	PM-10	Hexavalent	Total	
Rotary dryer (SCC 3-05-005-08)	1.7	0.41	7.6x10 ⁻⁵	0.70	
Rotary dryer with cyclone and fabric filter (SCC 3-05-005-08)	0.30	ND	3.7x10 ⁻⁵	0.13	
Tunnel kiln (SCC 3-05-005-09)	0.82	0.69	0.017	0.27	

EMISSION FACTOR RATING: D (except as noted)

^a Reference 6. Factors represent uncontrolled emissions. Factors for filterable PM are lb/ton of material processed. Factors for chromium are lb/ton of chromite ore processed. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution and filterable PM emission factor.

^c EMISSION FACTOR RATING: E.

Table 11.5-6. PARTICLE SIZE DISTRIBUTIONS FOR REFRACTORY MANUFACTURING: CHROMITE-MAGNESITE ORE DRYING AND FIRING^a

	Filterable PM ^b	Hexavalent Chromium ^c	Total Chromium ^c
Diameter (µm)	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter
Uncontrolled r	otary dryer (SCC 3-05-005-01)		
1	1.2	3.5	0.8
2	13	39	9
10	24	64	19
Uncontrolled t	unnel kiln (SCC 3-05-005-07)		
1	71	71	84
5	78	81	91
10	84	84	93

^a Reference 6. For filterable PM only. SCC = Source Classification Code.

^b EMISSION FACTOR RATING: D.

^c EMISSION FACTOR RATING: E.

or separated during the handling and forming of the fiber blankets in the curing oven. An oil is used in this process, and higher molecular weight organics may be emitted. However, these emissions generally are controlled with a fabric filter followed by incineration, at an expected overall efficiency in excess of 95 percent.

References For Section 11.5

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11.6 Portland Cement Manufacturing

11.6.1 Process Description¹⁻⁷

Portland cement is a fine powder, gray or white in color, that consists of a mixture of hydraulic cement materials comprising primarily calcium silicates, aluminates and aluminoferrites. More than 30 raw materials are known to be used in the manufacture of portland cement, and these materials can be divided into four distinct categories: calcareous, siliceous, argillaceous, and ferrifrous. These materials are chemically combined through pyroprocessing and subjected to subsequent mechanical processing operations to form gray and white portland cement. Gray portland cement is used for structural applications and is the more common type of cement produced. White portland cement has lower iron and manganese contents than gray portland cement and is used primarily for decorative purposes. Portland cement manufacturing plants are part of hydraulic cement manufacturing, which also includes natural, masonry, and pozzolanic cement. The six-digit Source Classification Code (SCC) for portland cement plants with wet process kilns is 3-05-006, and the six-digit SCC for plants with dry process kilns is 3-05-007.

Portland cement accounts for 95 percent of the hydraulic cement production in the United States. The balance of domestic cement production is primarily masonry cement. Both of these materials are produced in portland cement manufacturing plants. A diagram of the process, which encompasses production of both portland and masonry cement, is shown in Figure 11.6-1. As shown in the figure, the process can be divided into the following primary components: raw materials acquisition and handling, kiln feed preparation, pyroprocessing, and finished cement grinding. Each of these process components is described briefly below. The primary focus of this discussion is on pyroprocessing operations, which constitute the core of a portland cement plant.

The initial production step in portland cement manufacturing is raw materials acquisition. Calcium, the element of highest concentration in portland cement, is obtained from a variety of calcareous raw materials, including limestone, chalk, marl, sea shells, aragonite, and an impure limestone known as "natural cement rock". Typically, these raw materials are obtained from open-face quarries, but underground mines or dredging operations are also used. Raw materials vary from facility to facility. Some quarries produce relatively pure limestone that requires the use of additional raw materials to provide the correct chemical blend in the raw mix. In other quarries, all or part of the noncalcarious constituents are found naturally in the limestone. Occasionally, pockets of pyrite, which can significantly increase emissions of sulfur dioxide (SO₂), are found in deposits of limestone, clays, and shales used as raw materials for portland cement. Because a large fraction (approximately one third) of the mass of this primary material is lost as carbon dioxide (CO₂) in the kiln, portland cement plants are located close to a calcareous raw material source whenever possible. Other elements included in the raw mix are silicon, aluminum, and iron. These materials are obtained from ores and minerals such as sand, shale, clay, and iron ore. Again, these materials are most commonly from open-pit quarries or mines, but they may be dredged or excavated from underwater deposits.

Either gypsum or natural anhydrite, both of which are forms of calcium sulfate, is introduced to the process during the finish grinding operations described below. These materials, also excavated from quarries or mines, are generally purchased from an external source, rather than obtained directly from a captive operation by the cement plant. The portland cement manufacturing industry is relying increasingly on replacing virgin materials with waste materials or byproducts from other manufacturing operations, to the extent that such replacement can be implemented without adversely

EMISSION SOURCE SCC Dry process-general 3-05-006-Wet process-general 3-05-007-A. Kiln -06 B. Raw material unloading -07 (T) PM EMISSIONS C. Raw material piles -08 D. Primary crushing -09 E. Secondary crushing -10 (2) GASEOUS EMISSIONS F. Screening -11 (2) (1)G. Raw material transfer -12 H. Raw material grinding/drying -13 — — OPTIONAL PROCESS STEP I. Clinker cooler -14 J. Clinker piles -15 K. Clinker transfer -16 OPTIONAL L Clinker grinding -17 PREHEATER/ PRECALCINER M. Cement silos -18 N. Cement load out -19 \odot O. Raw mill feed bett -24 $(\mathbf{1})$ (2)P. Raw mill weigh hopper -25 G Q. Raw mill air separator -26 DRY PROCESS R. Finish grinding mill feed belt -27 $(\mathbf{1})$ $(\mathbf{1})$ (1)S. Finish grinding mill weigh hopper -28 T. Finish grinding mill air separator -29 U. Preheater kiln 3-05-006-22 G OPTIONAL PREHEATER RAW MATERIAL V. Preheater/precalciner kiln 3-05-006-22 DRY MIXING QUARRYING PREPARATION AND BLENDING RAW PROPORTIONING 0 AND GRINDING) Ð GYPSUM ➀ G (\mathbf{f}) (\mathbf{f}) (1)2 ᡅ G (2) PROCESSING RAW MATERIALS (PRIMARY AND SECONDARY ROTARY SHIPMENT G STORAGE KILN MILL CRUSHING) ⊘ RS 働 N J \odot BCOEFOPQ RAW MATERIAL SLURRY MIXING AND ി G G PREPARATION (PROPORTIONING AND GRINDING) . . BLENDING AIR SEPARATOR Ð ☽ FUEL WATER WET PROCESS



EMISSION FACTORS

affecting plant operations, product quality or the environment. Materials that have been used include fly ash, mill scale, and metal smelting slags.

The second step in portland cement manufacture is preparing the raw mix, or kiln feed, for the pyroprocessing operation. Raw material preparation includes a variety of blending and sizing operations that are designed to provide a feed with appropriate chemical and physical properties. The raw material processing operations differ somewhat for wet and dry processes, as described below.

Cement raw materials are received with an initial moisture content varying from 1 to more than 50 percent. If the facility uses dry process kilns, this moisture is usually reduced to less than 1 percent before or during grinding. Drying alone can be accomplished in impact dryers, drum dryers, paddle-equipped rapid dryers, air separators, or autogenous mills. However, drying can also be accomplished during grinding in ball-and-tube mills or roller mills. While thermal energy for drying can be supplied by exhaust gases from separate, direct-fired coal, oil, or gas burners, the most efficient and widely used source of heat for drying is the hot exit gases from the pyroprocessing system.

Materials transport associated with dry raw milling systems can be accomplished by a variety of mechanisms, including screw conveyors, belt conveyors, drag conveyors, bucket elevators, air slide conveyors, and pneumatic conveying systems. The dry raw mix is pneumatically blended and stored in specially constructed silos until it is fed to the pyroprocessing system.

In the wet process, water is added to the raw mill during the grinding of the raw materials in ball or tube mills, thereby producing a pumpable slurry, or slip, of approximately 65 percent solids. The slurry is agitated, blended, and stored in various kinds and sizes of cylindrical tanks or slurry basins until it is fed to the pyroprocessing system.

The heart of the portland cement manufacturing process is the pyroprocessing system. This system transforms the raw mix into clinkers, which are gray, glass-hard, spherically shaped nodules that range from 0.32 to 5.1 centimeters (cm) (0.125 to 2.0 inches [in.]) in diameter. The chemical reactions and physical processes that constitute the transformation are quite complex, but they can be viewed conceptually as the following sequential events:

- 1. Evaporation of free water;
- 2. Evolution of combined water in the argillaceous components;
- 3. Calcination of the calcium carbonate (CaCO₃) to calcium oxide (CaO);
- 4. Reaction of CaO with silica to form dicalcium silicate;
- 5. Reaction of CaO with the aluminum and iron-bearing constituents to form the liquid phase;
- 6. Formation of the clinker nodules;
- 7. Evaporation of volatile constituents (e. g., sodium, potassium, chlorides, and sulfates); and
- 8. Reaction of excess CaO with dicalcium silicate to form tricalcium silicate.

This sequence of events may be conveniently divided into four stages, as a function of location and temperature of the materials in the rotary kiln.

- 1. Evaporation of uncombined water from raw materials, as material temperature increases to 100°C (212°F);
- 2. Dehydration, as the material temperature increases from 100°C to approximately 430°C (800°F) to form oxides of silicon, aluminum, and iron;
- 3. Calcination, during which carbon dioxide (CO₂) is evolved, between 900°C (1650°F) and 982°C (1800°F), to form CaO; and
- 4. Reaction, of the oxides in the burning zone of the rotary kiln, to form cement clinker at temperatures of approximately 1510°C (2750°F).

Rotary kilns are long, cylindrical, slightly inclined furnaces that are lined with refractory to protect the steel shell and retain heat within the kiln. The raw material mix enters the kiln at the elevated end, and the combustion fuels generally are introduced into the lower end of the kiln in a countercurrent manner. The materials are continuously and slowly moved to the lower end by rotation of the kiln. As they move down the kiln, the raw materials are changed to cementitious or hydraulic minerals as a result of the increasing temperature within the kiln. The most commonly used kiln fuels are coal, natural gas, and occasionally oil. The use of supplemental fuels such as waste solvents, scrap rubber, and petroleum coke has expanded in recent years.

Five different processes are used in the portland cement industry to accomplish the pyroprocessing step: the wet process, the dry process (long dry process), the semidry process, the dry process with a preheater, and the dry process with a preheater/precalciner. Each of these processes accomplishes the physical/chemical steps defined above. However, the processes vary with respect to equipment design, method of operation, and fuel consumption. Generally, fuel consumption decreases in the order of the processes listed. The paragraphs below briefly describe the process, starting with the wet process and then noting differences in the other processes.

In the wet process and long dry process, all of the pyroprocessing activity occurs in the rotary kiln. Depending on the process type, kilns have length-to-diameter ratios in the range of 15:1 to 40:1. While some wet process kilns may be as long as 210 m (700 ft), many wet process kilns and all dry process kilns are shorter. Wet process and long dry process pyroprocessing systems consist solely of the simple rotary kiln. Usually, a system of chains is provided at the feed end of the kiln in the drying or preheat zones to improve heat transfer from the hot gases to the solid materials. As the kiln rotates, the chains are raised and exposed to the hot gases. Further kiln rotation causes the hot chains to fall into the cooler materials at the bottom of the kiln, thereby transferring the heat to the load.

Dry process pyroprocessing systems have been improved in thermal efficiency and productive capacity through the addition of one or more cyclone-type preheater vessels in the gas stream exiting the rotary kiln. This system is called the preheater process. The vessels are arranged vertically, in series, and are supported by a structure known as the preheater tower. Hot exhaust gases from the rotary kiln pass countercurrently through the downward-moving raw materials in the preheater vessels. Compared to the simple rotary kiln, the heat transfer rate is significantly increased, the degree of heat utilization is greater, and the process time is markedly reduced by the intimate contact of the solid particles with the hot gases. The improved heat transfer allows the length of the rotary kiln to be reduced. The hot gases from the preheater tower are often used as a source of heat for

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drying raw materials in the raw mill. Because the catch from the mechanical collectors, fabric filters, and/or electrostatic precipitators (ESP) that follow the raw mill is returned to the process, these devices are considered to be production machines as well as pollution control devices.

Additional thermal efficiencies and productivity gains have been achieved by diverting some fuel to a calciner vessel at the base of the preheater tower. This system is called the preheater/precalciner process. While a substantial amount of fuel is used in the precalciner, at least 40 percent of the thermal energy is required in the rotary kiln. The amount of fuel that is introduced to the calciner is determined by the availability and source of the oxygen for combustion in the calciner. Calciner systems sometimes use lower-quality fuels (e. g., less-volatile matter) as a means of improving process economics.

Preheater and precalciner kiln systems often have an alkali bypass system between the feed end of the rotary kiln and the preheater tower to remove the undesirable volatile constituents. Otherwise, the volatile constituents condense in the preheater tower and subsequently recirculate to the kiln. Buildup of these condensed materials can restrict process and gas flows. The alkali content of portland cement is often limited by product specifications because excessive alkali metals (i. e., sodium and potassium) can cause deleterious reactions in concrete. In a bypass system, a portion of the kiln exit gas stream is withdrawn and quickly cooled by air or water to condense the volatile constituents to fine particles. The solid particles, containing the undesirable volatile constituents, are removed from the gas stream and thus the process by fabric filters and ESPs.

The semidry process is a variation of the dry process. In the semidry process, the water is added to the dry raw mix in a pelletizer to form moist nodules or pellets. The pellets then are conveyed on a moving grate preheater before being fed to the rotary kiln. The pellets are dried and partially calcined by hot kiln exhaust gases passing through the moving grate.

Regardless of the type of pyroprocess used, the last component of the pyroprocessing system is the clinker cooler. This process step recoups up to 30 percent of the heat input to the kiln system, locks in desirable product qualities by freezing mineralogy, and makes it possible to handle the cooled clinker with conventional conveying equipment. The more common types of clinker coolers are (1) reciprocating grate, (2) planetary, and (3) rotary. In these coolers, the clinker is cooled from about 1100 °C to 93 °C (2000 °F to 200 °F) by ambient air that passes through the clinker and into the rotary kiln for use as combustion air. However, in the reciprocating grate cooler, lower clinker discharge temperatures are achieved by passing an additional quantity of air through the clinker. Because this additional air cannot be utilized in the kiln for efficient combustion, it is vented to the atmosphere, used for drying coal or raw materials, or used as a combustion air source for the precalciner.

The final step in portland cement manufacturing involves a sequence of blending and grinding operations that transforms clinker to finished portland cement. Up to 5 percent gypsum or natural anhydrite is added to the clinker during grinding to control the cement setting time, and other specialty chemicals are added as needed to impart specific product properties. This finish milling is accomplished almost exclusively in ball or tube mills. Typically, finishing is conducted in a closed-circuit system, with product sizing by air separation.

11.6.2 Emissions And Controls^{1,3-7}

Particulate matter (PM and PM-10), nitrogen oxides (NO_x) , sulfur dioxide (SO_2) , carbon monoxide (CO), and CO₂ are the primary emissions in the manufacture of portland cement. Small quantities of volatile organic compounds (VOC), ammonia (NH_3) , chlorine, and hydrogen chloride

(HCl), also may be emitted. Emissions may also include residual materials from the fuel and raw materials or products of incomplete combustion that are considered to be hazardous. Because some facilities burn waste fuels, particularly spent solvents in the kiln, these systems also may emit small quantities of additional hazardous organic pollutants. Also, raw material feeds and fuels typically contain trace amounts of heavy metals that may be emitted as a particulate or vapor.

Sources of PM at cement plants include (1) quarrying and crushing, (2) raw material storage, (3) grinding and blending (in the dry process only), (4) clinker production, (5) finish grinding, and (6) packaging and loading. The largest emission source of PM within cement plants is the pyroprocessing system that includes the kiln and clinker cooler exhaust stacks. Often, dust from the kiln is collected and recycled into the kiln, thereby producing clinker from the dust. However, if the alkali content of the raw materials is too high, some or all of the dust is discarded or leached before being returned to the kiln. In many instances, the maximum allowable cement alkali content of 0.6 percent (calculated as sodium oxide) restricts the amount of dust that can be recycled. Bypass systems sometimes have a separate exhaust stack. Additional sources of PM are raw material storage piles, conveyors, storage silos, and unloading facilities. Emissions from portland cement plants constructed or modified after August 17, 1971 are regulated to limit PM emissions from portland cement kilns to 0.15 kg/Mg (0.30 lb/ton) of feed (dry basis), and to limit PM emissions from clinker coolers to 0.050 kg/Mg (0.10 lb/ton) of feed (dry basis).

Oxides of nitrogen are generated during fuel combustion by oxidation of chemically-bound nitrogen in the fuel and by thermal fixation of nitrogen in the combustion air. As flame temperature increases, the amount of thermally generated NO_x increases. The amount of NO_x generated from fuel increases with the quantity of nitrogen in the fuel. In the cement manufacturing process, NO_x is generated in both the burning zone of the kiln and the burning zone of a precalcining vessel. Fuel use affects the quantity and type of NO_x generated. For example, in the kiln, natural gas combustion with a high flame temperature and low fuel nitrogen generates a larger quantity of NO_x than does oil or coal, which have higher fuel nitrogen but which burn with lower flame temperatures. The opposite may be true in a precalciner. Types of fuels used vary across the industry. Historically, some combination of coal, oil, and natural gas was used, but over the last 15 years, most plants have switched to coal, which generates less NO_x than does oil or gas. However, in recent years a number of plants have switched to systems that burn a combination of coal and waste fuel. The effect of waste fuel use on NO_x emissions is not clearly established.

Sulfur dioxide may be generated both from the sulfur compounds in the raw materials and from sulfur in the fuel. The sulfur content of both raw materials and fuels varies from plant to plant and with geographic location. However, the alkaline nature of the cement provides for direct absorption of SO_2 into the product, thereby mitigating the quantity of SO_2 emissions in the exhaust stream. Depending on the process and the source of the sulfur, SO_2 absorption ranges from about 70 percent to more than 95 percent.

The CO₂ emissions from portland cement manufacturing are generated by two mechanisms. As with most high-temperature, energy-intensive industrial processes, combusting fuels to generate process energy releases substantial quantities of CO₂. Substantial quantities of CO₂ also are generated through calcining of limestone or other calcareous material. This calcining process thermally decomposes CaCO₃ to CaO and CO₂. Typically, portland cement contains the equivalent of about 63.5 percent CaO. Consequently, about 1.135 units of CaCO₃ are required to produce 1 unit of cement, and the amount of CO₂ released in the calcining process is about 500 kilograms (kg) per Mg of portland cement produced (1,000 pounds [lb] per ton of cement). Total CO₂ emissions from the pyroprocess depend on energy consumption and generally fall in the range of 0.85 to 1.35 Mg of CO₂ per Mg of clinker.

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In addition to CO_2 emissions, fuel combustion at portland cement plants can emit a wide range of pollutants in smaller quantities. If the combustion reactions do not reach completion, CO and volatile organic pollutants, typically measured as total organic compounds (TOC), VOC, or organic condensable particulate, can be emitted. Incomplete combustion also can lead to emissions of specific hazardous organic air pollutants, although these pollutants are generally emitted at substantially lower levels than CO or TOC.

Emissions of metal compounds from portland cement kilns can be grouped into three general classes: volatile metals, including mercury (Hg) and thallium (Tl); semivolatile metals, including antimony (Sb), cadmium (Cd), lead (Pb), selenium (Se), zinc (Zn), potassium (K), and sodium (Na); and refractory or nonvolatile metals, including barium (Ba), chromium (Cr), arsenic (As), nickel (Ni), vanadium (V), manganese (Mn), copper (Cu), and silver (Ag). Although the partitioning of these metal groups is affected by kiln operating conditions, the refractory metals tend to concentrate in the clinker, while the volatile and semivolatile metals tend to be discharged through the primary exhaust stack and the bypass stack, respectively.

Fugitive dust sources in the industry include quarrying and mining operations, vehicle traffic during mineral extraction and at the manufacturing site, raw materials storage piles, and clinker storage piles. The measures used to control emissions from these fugitive dust sources are comparable to those used throughout the mineral products industries. Vehicle traffic controls include paving and road wetting. Controls that are applied to other open dust sources include water sprays with and without surfactants, chemical dust suppressants, wind screens, and process modifications to reduce drop heights or enclose storage operations. Additional information on these control measures can be found in Chapter 13 of AP-42, "Miscellaneous Sources".

Process fugitive emission sources include materials handling and transfer, raw milling operations in dry process facilities, and finish milling operations. Typically, emissions from these processes are captured by a ventilation system and collected in fabric filters. Some facilities use an air pollution control system comprising one or more mechanical collectors with a fabric filter in series. Because the dust from these units is returned to the process, they are considered to be process units as well as air pollution control devices. The industry uses shaker, reverse air, and pulse jet filters as well as some cartridge units, but most newer facilities use pulse jet filters. For process fugitive operations, the different systems are reported to achieve typical outlet PM loadings of 45 milligrams per cubic meter (mg/m^3) (0.02 grains per actual cubic foot [gr/acf]).

In the pyroprocessing units, PM emissions are controlled by fabric filters (reverse air, pulse jet, or pulse plenum) and electrostatic precipitators (ESP). Typical control measures for the kiln exhaust are reverse air fabric filters with an air-to-cloth ratio of $0.41:1 \text{ m}^3/\text{min/m}^2$ (1.5:1 acfm/ft²) and ESP with a net surface collection area of 1,140 to 1,620 m²/1,000 m³ (350 to 500 ft²/1,000 ft³). These systems are reported to achieve outlet PM loadings of 45 mg/m³ (0.02 gr/acf). Clinker cooler systems are controlled most frequently with pulse jet or pulse plenum fabric filters. A few gravel bed filters also have been used to control clinker cooler emissions. Typical outlet PM loadings are identical to those reported for kilns.

Cement kiln systems have highly alkaline internal environments that can absorb up to 95 percent of potential SO_2 emissions. However, in systems that have sulfide sulfur (pyrites) in the kiln feed, the sulfur absorption rate may be as low as 70 percent without unique design considerations or changes in raw materials. The cement kiln system itself has been determined to provide substantial SO_2 control. Fabric filters on cement kilns are also reported to absorb SO_2 . Generally, substantial control is not achieved. An absorbing reagent (e. g., CaO) must be present in the filter cake for SO_2 capture to occur. Without the presence of water, which is undesirable in the operation of a fabric

filter, $CaCO_3$ is not an absorbing reagent. It has been observed that as much as 50 percent of the SO_2 can be removed from the pyroprocessing system exhaust gases when this gas stream is used in a raw mill for heat recovery and drying. In this case, moisture and calcium carbonate are simultaneously present for sufficient time to accomplish the chemical reaction with SO_2 .

Tables 11.6-1 and 11.6-2 present emission factors for PM emissions from portland cement manufacturing kilns and clinker coolers. Tables 11.6-3 and 11.6-4 present emission factors for PM emissions from raw material and product processing and handling. Particle size distributions for emissions from wet process and dry process kilns are presented in Table 11.6-5, and Table 11.6-6 presents the particle size distributions for emissions from clinker coolers. Emission factors for SO₂, NO_x, CO, CO₂, and TOC emissions from portland cement kilns are summarized in Tables 11.6-7 and 11.6-8. Table 11.6-9 summarizes emission factors for other pollutant emissions from portland cement kilns.

Because of differences in the sulfur content of the raw material and fuel and in process operations, a mass balance for sulfur may yield a more representative emission factor for a specific facility than the SO₂ emission factors presented in Tables 11.6-7 and 11.6-8. In addition, CO₂ emission factors estimated using a mass balance on carbon may be more representative for a specific facility than the CO₂ emission factors presented in Tables 11.6-7 and 11.6-8.

Table 11.6-1 (Metric Units).	EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING
	KILNS AND CLINKER COOLERS ^a

	Filterable ^b			Condensable ^c				
Process	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Wet process kiln (SCC 3-05-007-06)	65 ^d	D	16 ^e	D	ND		ND	
Wet process kiln with ESP (SCC 3-05-007-06)	0.38 ^f	С	0.33 ^g	D	0.076 ^h	D	ND	
Wet process kiln with fabric filter (SCC 2-05-007-06)	0.23 ^j	Ε	ND		0.10 ^j	E	ND	
Wet process kiln with cooling tower, multiclone, and ESP (SCC 3-05-007-06)	0.10 ^k	E	ND		0.14 ^k	Ε	ND	
Dry process kiln with ESP (SCC 3-05-006-06)	0.50 ^m	D	ND		0.19 ^m	D	ND	
Dry process kiln with fabric filter (SCC 3-05-006-06)	0.10 ⁿ	D	0.084 ^p	D	0.45 ⁿ	D	ND	
Preheater kiln (SCC 3-05-006-22)	130 ^q	D	ND		ND		ND	
Preheater kiln with ESP (SCC 3-05-006-22)	0.13 ^r	D	ND		ND		ND	
Preheater kiln with fabric filter (SCC 3-05-006-22)	0.13 ^s	С	ND		0.017 ^t	D	ND	
Preheater/precalciner kiln with ESP (SCC 3-05-006-23)	0.024 ^u	D	ND		ND		ND	
Preheater/precalciner process kiln with fabric filter (SCC 3-05-006-23)	0.10 ^v	D	ND		ND		ND	
Preheater/precalciner process kiln with PM controls (SCC 3-05-006-23)	ND		ND		0.078 ^w	D	ND	

Table 11.6-1 (cont.).

	Filterable ^b Condensat						sable ^c	
Process	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Clinker cooler with ESP (SCC 3-05-006-14)	0.048 ^x	D	ND		0.0038 ^x	D	ND	
Clinker cooker with fabric filter (SCC 3-05-006-14)	0.068 ^y	D	ND		0.0084 ^z	D	ND	
Clinker cooler with gravel bed filter (SCC 3-05-006-14)	0.11 ^{aa}	D	0.084 ^{bb}	D	0.0045 ^{cc}	D	ND	

^a Factors represent uncontrolled emissions unless, otherwise noted. Factors are kg/Mg of clinker produced, unless noted. SCC = Source Classification Code. ND = no data. ESP = electrostatic precipitator.

^b Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Condensable PM is that collected in the impinger portion of a PM sampling train.

^d References 20,26.

^e References 3,20,26.

^f References 8-9,18,20,25-26,32,34-36,41-44,60,64.

^g References 3,8-9,18,20,25-26,32,34-36,41-44,60,64.

- ^k Reference 21.
- ^m References 19,21.
- ⁿ Reference 23.
- ^p References 3,23.
- ^q Reference 17.
- ^r Reference 31.
- ^s References 17,47-50,61.
- ^t Reference 51.
- ^u Reference 37.
- v References 30,33,51,56-59,63
- ^w References 30,33,37,51,59.
- ^x Reference 8.
- ^y References 9,12,27,30,33.

^z References 9,12,30. ^{aa}References 22,29,31 ^{bb}References 3,22,29,31 ^{cc}References 22,29

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^h References 8-9,20,64.

^j Reference 14.

Table 11.6-2 (English Units).	EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING
	KILNS AND CLINKER COOLERS ^a

		Filter	ıble ^b	Filterable ^b Condensable ^c				
Process	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Wet process kiln (SCC 3-05-007-06)	130 ^d	D	31°	D	ND		ND	
Wet process kiln with ESP (SCC 3-05-007-06)	0.77 ^f	С	0.65 ^g	D	0.15 ^h	D	ND	
Wet process kiln with fabric filter (SCC 3-05-007-06)	0.46 ^j	Е	ND		0.20 ^j	Е	ND	
Wet process kiln with cooling tower, multiclone, and ESP (SCC 3-05-007-06)	0.20 ^k	Е	ND		0.29 ^k	Е	ND	
Dry process kiln with ESP (SCC 3-05-006-06)	1.0 ^m	D	ND		0.38 ^m	D	ND	
Dry process kiln with fabric filter (SCC 3-05-006-06)	0.20 ⁿ	D	0.17 ^p	D	0.89 ⁿ	D	ND	
Preheater kiln (SCC 3-05-006-22)	250 ^q	D	ND		ND		ND	
Preheater kiln with ESP (SCC 3-05-006-22)	0.26 ^r	D	ND		ND		ND	
Prchcater kiln with fabric filter (SCC 3-05-006-22)	0.25 ^s	C	ND		0.033 ^t	D	ND	
Preheater/precalciner kiln with ESP (SCC 3-05-006-23)	0.048 ^u	D	ND		ND		ND	
Preheater/precalciner process kiln with fabric filter (SCC 3-05-006-23)	0.21 ^v	D	ND		ND		ND	
Preheater/precalciner process kiln with PM controls (SCC 3-05-006-23)	ND		ND		0.16 ^w	D	ND	

Table 11.6-2 (cont.).

		Filter	able ^b		Condensable ^c				
Process	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING	
Clinker cooler with ESP (SCC 3-05-006-14)	0.096 ^x	D	ND		0.0075 ^x	D	ND		
Clinker cooker with fabric filter (SCC 3-05-006-14)	0.13 ^y	D	ND		0.017 ^z	D	ND		
Clinker cooler with gravel bed filter (SCC 3-05-006-14)	0.21 ^{aa}	D	0.16 ^{bb}	D	0.0090 ^{cc}	D	ND		

^a Factors represent uncontrolled emissions unless otherwise noted. Factors are lb/ton of clinker produced unless noted. SCC = Source Classification Code. ND = no data. ESP = electrostatic precipitator.

^b Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Condensable PM is that collected in the impinger portion of a PM sampling train.

^d References 20,26.

^e References 3,20,26.

^f References 8-9,18,20,25-26,32,34-36,41-44,60,64.

^g References 3,8-9,18,20,25-26,32,34-36,41-44,60,64.

^h References 8-9,20,64.

^j Reference 14.

^k Reference 21.

^m References 19,21.

- ⁿ Reference 23.
- ^p References 3,23.
- ^q Reference 17.
- ^r Reference 31.
- ^s References 17,47-50,61.
- ^t Reference 51.
- ^u Reference 37.
- ^v References 30,33,51,56-59,63
- ^w References 30,33,37,51,59.
- ^x Reference 8.
- ^y References 9,12,27,30,33. ^zReferences 9,12,30.

^{aa}References 22,29,31 ^{bb}References 3,22,29,31 ^{cc}References 22,29

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Table 11.6-3 (Metric Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING RAW MATERIAL AND PRODUCT PROCESSING AND HANDLING^a

	Filterable ^b						
Process	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING			
Raw mill with fabric filter (SCC 3-05-006-13)	0.0062°	D	ND				
Raw mill feed belt with fabric filter (SCC 3-05-006-24)	0.0016 ^d	E	ND				
Raw mill weigh hopper with fabric filter (SCC 3-05-006-25)	0.010 ^e	E	ND				
Raw mill air separator with fabric filter (SCC 3-05-006-26)	0.016 ^e	E	ND				
Finish grinding mill with fabric filter (SCC 3-05-006-17, 3-05-007-17)	0.0042 ^f	D	ND				
Finish grinding mill feed belt with fabric filter (SCC 3-05-006-27, 3-05-007-27)	0.0012 ^d	E	ND				
Finish grinding mill weigh hopper with fabric filter (SCC 3-05-006-28, 3-05-007-28)	0.0047 ^e	E	ND				
Finish grinding mill air separator with fabric filter (SCC 3-05-006-29, 3-05-007-29)	0.014 ^g	D	ND				
Primary limestone crushing with fabric filter (SCC 3-05-006-09) ^h	0.00050	E	ND	,			
Primary limestone screening with fabric filter (SCC 3-05-006-11) ^h	0.00011	E	ND				
Limestone transfer with fabric filter (SCC 3-05-006-12) ^h	1.5 x 10 ⁻⁵	E	ND				
Secondary limestone screening and crushing with fabric filter (SCC 3-05-006-10 + -11, 3-05-007-10 + -11) ^h	0.00016	E	ND				

^a Factors represent uncontrolled emissions, unless otherwise noted. Factors are kg/Mg of material _{4b}process, unless noted. SCC = Source Classification Code. ND = no data.

Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

- ^f References 10,12,15,56-57.

^g References 10,15. ^h Reference 16. Alternatively, emission factors from Section 11.19.2, "Crushed Stone Processing", can be used for similar processes and equipment.

^c References 15,56-57. ^d Reference 57. ^e Reference 15.

Table 11.6-4 (English Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING RAW MATERIAL AND PRODUCT PROCESSING AND HANDLING^a

	Filterable ^b					
Process	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING		
Raw mill with fabric filter (SCC 3-05-006-13)	0.012 ^c	D	ND			
Raw mill feed belt with fabric filter (SCC 3-05-006-24)	0.0031 ^d	E	ND			
Raw mill weigh hopper with fabric filter (SCC 3-05-006-25)	0.019 ^e	Е	ND			
Raw mill air separator with fabric filter (SCC 3-05-006-26)	0.032 ^e	Е	ND			
Finish grinding mill with fabric filter (SCC 3-05-006-17, 3-05-007-17)	0.0080 ^f	E	ND			
Finish grinding mill feed belt with fabric filter (SCC 3-05-006-27, 3-05-007-27)	0.0024 ^d	E	ND			
Finish grinding mill weigh hopper with fabric filter (SCC 3-05-006-28, 3-05-007-28)	0.0094 ^e	E	ND			
Finish grinding mill air separator with fabric filter (SCC 3-05-006-29, 3-05-007-29)	0.028 ^g	D	ND			
Primary limestone crushing with fabric filter (SCC 3-05-006-09) ^h	0.0010	E	ND			
Primary limestone screening with fabric filter (SCC 3-05-006-11) ^h	0.00022	Е	ND			
Limestone transfer with fabric filter (SCC 3-05-006-12) ^h	2.9 x 10 ⁻⁵	E	ND			
Secondary limestone screening and crushing with fabric filter (SCC 3-05-006-10 + -11, 3-05-007-10 + -11) ^h	0.00031	E	ND			

^a Factors represent uncontrolled emissions, unless otherwise noted. Factors are lb/ton of material processed, unless noted. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c References 15,56-57.

^d Reference 57.

^e Reference 15.

^f References 10, 12, 15, 56-57.

^g References 10,15.

^h Reference 16. Alternatively, emission factors from the Section 11.19.2, "Crushed Stone Processing", can be used for similar processes and equipment.

Table 11.6-5.SUMMARY OF AVERAGE PARTICLE SIZE DISTRIBUTION
FOR PORTLAND CEMENT KILNS^a

	Cumulative Mass Percent Equal To Or Less Than Stated Size								
	Uncon	trolled	Controlled						
Particle Size, μm	Wet process (SCC 3-05-007-06)	Dry process (SCC 3-05-006-06)	Wet process With ESP (SCC 3-05-007-06)	Dry process With FF (SCC 3-05-006-06)					
2.5	7	18	64	45					
5.0	20	ND	83	77					
10.0	24	42	85	84					
15.0	35	44	91	89					
20.0	57	ND	98	100					

^a Reference 3. SCC = Source Classification Code. ND = no data.

Table 11.6-6. SUMMARY OF AVERAGE PARTICLE SIZE DISTRIBUTION FOR PORTLAND CEMENT CLINKER COOLERS^a

	Cumulative Mass Percent Equal To Or Less Than Stated Size							
Particle Size, μ m	Uncontrolled (SCC 3-05-006-14, 3-05-007-14)	With Gravel Bed Filter (SCC 3-05-006-14, 3-05-007-14)						
2.5	0.54	40						
5.0	1.5	64						
10.0	8.6	76						
15.0	21	84						
20.0	34	89						

^a Reference 3. SCC = Source Classification Code.

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Process	so2 ^b	EMISSION FACTOR RATING	NO _x	EMISSION FACTOR RATING	со	EMISSION FACTOR RATING	CO2°	EMISSION FACTOR RATING	тос	EMISSION FACTOR RATING
Wet process kiln (SCC 3-05-007-06)	4.1 ^d	С	3.7¢	D	0.060 ^f	D	1,100 ^g	D	0.014 ^f	D
Long dry process kiln (SCC 3-05-006-06)	4.9 ^h	D	3.0 ^j	D	0.11 ^k	Е	900 ^m	D	0.014 ⁿ	E
Preheater process kiln (SCC 3-05-006-22)	0.27 ^p	D	2.4 ^q	D	0.49 ^r	D	900 ^s	с	0.090 ^t	D
Preheater/precalciner kiln (SCC 3-05-006-23)	0.54 ^u	D	2.1 ^v	D	1.8 ^w	D	900 ^x	Е	0.059 ^y	D
Preheater/precalciner kiln with spray tower (SCC 3-05-006-23)	0.50 ^z	E	ND		ND		ND		ND	

Table 11.6-7 (Metric Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING^a

^a Factors represent uncontrolled emissions unless otherwise noted. Factors are kg/Mg of clinker produced, unless noted. SCC = Source Classification Code. ND = no data. ^b Mass balance on sulfur may yield a more representative emission factor for a specific facility than the SO₂ emission factors presented in

this table.

^c Mass balance on carbon may yield a more representative emission factor for a specific facility than the CO₂ emission factors presented in this table.

- ^d References 20,25-26,32,34-36,41-44,60,64.
- ^e References 26,34-36,43,64.
- ^f Reference 64.
- ^g References 25-26,32,34-36,44,60,64.
- ^h References 11,19,39,40.
- ^j References 11,38-40,65.
- k References 39,65.
- ^m References 11,21,23,65.
- ⁿ References 40,65. TOC as measured by Method 25A or equivalent.
- ^p References 47-50.
- ^q References 48-50.
- ^r Reference 49.
- ^s References 24,31,47-50,61.

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Table 11.6-7 (cont.).

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^t Reference 49; total organic compounds as measured by Method 25A or equivalent.
^u References 28,30,33,37,53,56-59.
^v References 28,30,37,56-58,63.
^x References 24,31,47-50,61. Based on test data for preheater kilns; should be considered an upper limit.
^y References 30,33,56,63; total organic compounds as measured using Method 25A or equivalent.

^z Reference 54.

Process	SO. ^b	EMISSION FACTOR RATING	NO	EMISSION FACTOR RATING	C 0	EMISSION FACTOR RATING	CO.°	EMISSION FACTOR RATING	TOC	EMISSION FACTOR RATING
Wet process kiln (SCC 3-05-007-06)	8.2 ^d	C	7.4°	D	0.12 ^f	D	2,100 ^g	D	0.028 ^f	D
Long dry process kiln (SCC 3-05-006-06)	10 ^h	D	6.0 ^j	D	0.21 ^k	Е	1,800 ^m	D	0.028 ⁿ	E
Preheater process kiln (SCC 3-05-006-22)	0.55 ^p	D	4.8 ^q	D	0.98 ^r	D	1,800 ⁸	с	0.18 ^t	D
Preheater/precalciner kiln (SCC 3-05-006-23)	1.1 ^u	D	4.2 ^v	D	3.7₩	D	1,800 ^x	Е	0.12 ^y	D
Preheater/precalciner kiln with spray tower (SCC 3-05-006-23)	1.0 ^z	Е	ND		ND		ND		ND	

Table 11.6-8 (English Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING^a

^a Factors represent uncontrolled emissions unless otherwise noted. Factors are lb/ton of clinker produced, unless noted.

SCC = Source Classification Code. ND = no data.

^b Mass balance on sulfur may yield a more representative emission factor for a specific facility than the SO₂ emission factors presented in this table.

^c Mass balance on carbon may yield a more representative emission factor for a specific facility than the CO₂ emission factors presented in this table.

- ^d References 20,25-26,32,34-36,41-44,60,64.
- ^e References 26,34-36,43,64.
- ^f Reference 64.
- ^g References 25-26,32,34-36,44,60,64.
- ^h References 11,19,39-40.
- ^j References 11,38-40,65.
- ^k References 39,65.
- ^m References 11,21,23,65.
- ⁿ References 40,65. TOC as measured by Method 25A or equivalent.
- ^p References 47-50.
- ^q References 48-50.
- ^r Reference 49.
- ^s References 24,31,47-50,61.
- ^t Reference 49; total organic compounds as measured by Method 25A or equivalent.

Table 11.6-8 (cont.).

- ^u References 28,30,33,37,53,56-59.
 ^v References 28,30,33,37,45, and 56 to 59.
 ^w References 28,30,37,56-58,63.
 ^x References 24,31,47-50,61. Based on test data for preheater kilns; should be considered an upper limit.
 ^y References 30,33,56,63; total organic compounds as measured using Method 25A or equivalent.
- ^z Reference 54.

Pollutant	Type Of	Average Emi	ssion Factor	EMISSION	
Name	Control	kg/Mg	lb/ton	RATING	References
Inorganic Pollutants	•		•	L	
Silver (Ag)	FF	3.1x10 ⁻⁷	6.1x10 ⁻⁷	D	63
Aluminum (Al)	ESP	0.0065	0.013	E	65
Arsenic (As)	ESP	6.5x10 ⁻⁶	1.3x10 ⁻⁵	Е	65
Arsenic (As)	FF	6.0x10 ⁻⁶	1.2x10 ⁻⁵	D	63
Barium (Ba)	ESP	0.00018	0.00035	D	64
Barium (Ba)	FF	0.00023	0.00046	D	63
Beryllium (Be)	FF	3.3x10 ⁻⁷	6.6x10 ⁻⁷	D	63
Calcium (Ca)	ESP	0.12	0.24	Е	65
Cadmium (Cd)	ESP	4.2x10 ⁻⁶	8.3x10 ⁻⁶	D	64
Cadmium (Cd)	FF	1.1x10 ⁻⁶	2.2x10 ⁻⁶	D	63
Chloride (Cl)	ESP	0.34	0.68	Е	25,42-44
Chloride (Cl)	FF	0.0011	0.0021	D	63
Chromium (Cr)	ESP	3.9x10 ⁻⁶	7.7x10 ⁻⁶	Е	64
Chromium (Cr)	FF	7.0x10 ⁻⁵	0.00014	D	63
Copper (Cu)	FF	0.0026	0.0053	Е	62
Fluoride (F)	ESP	0.00045	0.00090	Е	43
Iron (Fe)	ESP	0.0085	0.017	Е	65
Hydrogen chloride (HCl)	ESP	0.025	0.049	Е	41,65
Hydrogen chloride (HCl)	FF	0.073	0.14	D	59,63
Mercury (Hg)	ESP	0.00011	0.00022	D	64
Mercury (Hg)	FF	1.2x10 ⁻⁵	2.4x10 ⁻⁵	D	11,63
Potassium (K)	ESP	0.0090	0.018	D	25,42-43
Manganese (Mn)	ESP	0.00043	0.00086	Е	65
Ammonia (NH ₃)	FF	0.0051	0.010	E	59
Ammonium (NH ₄)	ESP	0.054	0.11	D	25,42-44
Nitrate (NO ₃)	ESP	0.0023	0.0046	E	43
Sodium (Na)	ESP	0.020	0.038	D	25,42-44
Lead (Pb)	ESP	0.00036	0.00071	D	64
Lead (Pb)	FF	3.8x10 ⁻⁵	7.5x10 ⁻⁵	D	63
Sulfur trioxide (SO ₃)	ESP	0.042	0.086	E	25
Sulfur trioxide (SO ₃)	FF	0.0073	0.014	D	24,30,50
Sulfate (SO ₄)	ESP	0.10	0.20	D	25,42-44
Sulfate (SO ₄)	FF	0.0036	0.0072	D	30,33,52

Table 11.6-9 (Metric And English Units). SUMMARY OF NONCRITERIA POLLUTANT EMISSION FACTORS FOR PORTLAND CEMENT KILNS^a (SCC 3-05-006-06, 3-05-007-06, 3-05-006-22, 3-05-006-23)
Table 11.6-9 (c	ont.).
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	D. 11		Average Emi	ssion Factor	EMISSION	
	Name	Control	kg/Mg	lb/ton	RATING	References
	Selenium (Se)	ESP	7.5x10 ⁻⁵	0.00015	Е	65
	Selenium (Se)	FF	0.00010	0.00020	Е	62
	Thallium (Th)	FF	2.7x10 ⁻⁶	5.4x10 ⁻⁶	D	63
	Titanium (Ti)	ESP	0.00019	0.00037	Е	65
	Zinc (Zn)	ESP	0.00027	0.00054	D	64
	Zinc (Zn)	FF	0.00017	0.00034	D	63
Organic Pollu	itants		**************************************		· · · · · · · · · · · · · · · · · · ·	
CASRN ^b	Name					
35822-46-9	1,2,3,4,6,7,8 HpCDD	FF	1.1x10 ⁻¹⁰	2.2x10 ⁻¹⁰	Е	62
	C3 benzenes	ESP	1.3x10 ⁻⁶	2.6x10 ⁻⁶	Е	65
	C4 benzenes	ESP	3.0x10 ⁻⁶	6.0x10 ⁻⁶	Е	65
	C6 benzenes	ESP	4.6x10 ⁻⁷	9.2x10 ⁻⁷	Е	65
208-96-8	acenaphthylene	FF	5.9x10 ⁻⁵	0.00012	Е	62
67-64-1	acetone	ESP	0.00019	0.00037	D	64
100-52-7	benzaldehyde	ESP	1.2x10 ⁻⁵	2.4x10 ⁻⁵	Е	65
71-43-2	benzene	ESP	0.0016	0.0031	D	64
71-43-2	benzene	FF	0.0080	0.016	Е	62
	benzo(a)anthracene	FF	2.1x10 ⁻⁸	4.3x10 ⁻⁸	E	62
50-32-8	benzo(a)pyrene	FF	6.5x10 ⁻⁸	1.3x10 ⁻⁷	Е	62
205-99-2	benzo(b)fluoranthene	FF	2.8x10 ⁻⁷	5.6x10 ⁻⁷	Е	62
191-24-2	benzo(g,h,i)perylene	FF	3.9x10 ⁻⁸	7.8x10 ⁻⁸	Е	62
207-08-9	benzo(k)fluoranthene	FF	7.7x10 ⁻⁸	1.5x10 ⁻⁷	Е	62
65-85-0	benzoic acid	ESP	0.0018	0.0035	D	64
95-52-4	biphenyl	ESP	3.1x10 ⁻⁶	6.1x10 ⁻⁶	E	65
117-81-7	bis(2-ethylhexyl)phthalate	ESP	4.8x10 ⁻⁵	9.5x10 ⁻⁵	D	64
74-83-9	bromomethane	ESP	2.2x10 ⁻⁵	4.3x10 ⁻⁵	Е	64
75-15-0	carbon disulfide	ESP	5.5x10 ⁻⁵	0.00011	D	64
108-90-7	chlorobenzene	ESP	8.0x10 ⁻⁶	1.6x10 ⁻⁵	D	64
74-87-3	chloromethane	ESP	0.00019	0.00038	Е	64
218-01-9	chrysene	FF	8.1x10 ⁻⁸	1.6x10 ⁻⁷	Е	62
84-74-2	di-n-butylphthalate	ESP	2.1x10 ⁻⁵	4.1x10 ⁻⁵	D	64
53-70-3	dibenz(a,h)anthracene	FF	3.1x10 ⁻⁷	6.3x10 ⁻⁷	Е	62
101-41-4	ethylbenzene	ESP	9.5x10 ⁻⁶	1.9x10 ⁻⁵	D	64
206-44-0	fluoranthene	FF	4.4x10 ⁻⁶	8.8x10 ⁻⁶	Е	62
86-73-7	fluorene	FF	9.4x10 ⁻⁶	1.9x10 ⁻⁵	Е	62
50 -00 -0	formaldehyde	FF	0.00023	0.00046	Е	62

	Pollutant	Turne Of	Average Emission Factor		EMISSION	
CASRN ^b	Name	Control	kg/Mg	lb/ton	RATING	References
	freon 113	ESP	2.5x10 ⁻⁵	5.0x10 ⁻⁵	E	65
193-39-5	indeno(1,2,3-cd)pyrene	FF	4.3x10 ⁻⁸	8.7x10 ⁻⁸	Е	62
78-93-3	methyl ethyl ketone	ESP	1.5x10 ⁻⁵	3.0x10 ⁻⁵	Е	64-65
75-09-2	methylene chloride	ESP	0.00025	0.00049	Е	65
	methylnaphthalene	ESP	2.1x10 ⁻⁶	4.2x10 ⁻⁶	Е	65
91-20-3	naphthalene	FF	0.00085	0.0017	Е	62
91-20-3	naphthalene	ESP	0.00011	0.00022	D	64
85-01-8	phenanthrene	FF	0.00020	0.00039	E	62
108-95-2	phenol	ESP	5.5x10 ⁻⁵	0.00011	D	64
129-00-0	pyrene	FF	2.2x10 ⁻⁶	4.4x10 ⁻⁶	Е	62
100-42-5	styrene	ESP	7.5x10 ⁻⁷	1.5x10 ⁻⁶	Е	65
108-88-3	toluene	ESP	0.00010	0.00019	D	64
Í	total HpCDD	FF	2.0x10 ⁻¹⁰	3.9x10 ⁻¹⁰	Е	62
3268-87-9	total OCDD	FF	1.0x10 ⁻⁹	2.0x10 ⁻⁹	Е	62
	total PCDD	FF	1.4x10 ⁻⁹	2.7x10 ⁻⁹	Е	62
132-64-9	total PCDF	FF	1.4x10 ⁻¹⁰	2.9x10 ⁻¹⁰	Е	62
132-64-9	total TCDF	FF	1.4x10 ⁻¹⁰	2.9x10 ⁻¹⁰	Е	62
1330-20-7	xylenes	ESP	6.5x10 ⁻⁵	0.00013	D	64

Table 11.6-9 (cont.).

^a Factors are kg/Mg and lb/ton of clinker produced. SCC = Source Classification Code.
 ESP = electrostatic precipitator. FF = fabric filter.

^b Chemical Abstract Service Registry Number (organic compounds only).

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11.7 Ceramic Products Manufacturing

11.7.1 General¹⁻³

Ceramics are defined as a class of inorganic, nonmetallic solids that are subjected to high temperature in manufacture and/or use. The most common ceramics are composed of oxides, carbides, and nitrides. Silicides, borides, phosphides, tellurides, and selenides also are used to produce ceramics. Ceramic processing generally involves high temperatures, and the resulting materials are heat resistant or refractory.

Traditional ceramics refers to ceramic products that are produced from unrefined clay and combinations of refined clay and powdered or granulated nonplastic minerals. Often, traditional ceramics is used to refer to ceramics in which the clay content exceeds 20 percent. The general classifications of traditional ceramics are described below.

<u>Pottery</u> is sometimes used as a generic term for ceramics that contain clay and are not used for structural, technical, or refractory purposes.

<u>Whiteware</u> refers to ceramic ware that is white, ivory, or light gray in color after firing. Whiteware is further classified as earthenware, stoneware, chinaware, porcelain, and technical ceramics.

<u>Earthenware</u> is defined as glazed or unglazed nonvitreous (porous) clay-based ceramic ware. Applications for earthenware include artware, kitchenware, ovenware, tableware, and tile.

<u>Stoneware</u> is vitreous or semivitreous ceramic ware of fine texture, made primarily from nonrefractory fire clay or some combination of clays, fluxes, and silica that, when fired, has properties similar to stoneware made from fire clay. Applications for stoneware include artware, chemicalware, cookware, drainpipe, kitchenware, tableware, and tile.

<u>Chinaware</u> is vitreous ceramic ware of zero or low absorption after firing that are used for nontechnical applications. Applications for chinaware include artware, ovenware, sanitaryware, and tableware.

<u>Porcelain</u> is defined as glazed or unglazed vitreous ceramic ware used primarily for technical purposes. Applications for porcelain include artware, ball mill balls, ball mill liners, chemicalware, insulators, and tableware.

<u>Technical ceramics</u> include vitreous ceramic whiteware used for such products as electrical insulation, or for chemical, mechanical, structural, or thermal applications.

Ceramic products that are made from highly refined natural or synthetic compositions and designed to have special properties are referred to as advanced ceramics. Advanced ceramics can be classified according to application as electrical, magnetic, optical, chemical, thermal, mechanical, biological, and nuclear.

Most ceramic products are clay-based and are made from a single clay or one or more clays mixed with mineral modifiers such as quartz and feldspar. The types of commercial clays used for ceramics are primarily kaolin and ball clay.

11.7.2 Process Description^{1,3-5}

Figure 11.7-1 presents a general process flow diagram for ceramic products manufacturing. The basic steps include raw material procurement, beneficiation, mixing, forming, green machining, drying, presinter thermal processing, glazing, firing, final processing, and packaging. The following paragraphs describe these operations in detail.

11.7.2.1 Raw Material Procurement -

To begin the process, raw materials are transported and stored at the manufacturing facility. The raw materials used in the manufacture of ceramics range from relatively impure clay materials mined from natural deposits to ultrahigh purity powders prepared by chemical synthesis. Naturally occurring raw materials used to manufacture ceramics include silica, sand, quartz, flint, silicates, and aluminosilicates (e. g., clays and feldspar).

11.7.2.2 Beneficiation -

The next step in the process is beneficiation. Although chemically synthesized ceramic powders also require some beneficiation, the focus of this discussion is on the processes for beneficiating naturally occurring raw materials. The basic beneficiation processes include comminution, purification, sizing, classification, calcining, liquid dispersion, and granulation. Naturally occurring raw materials often undergo some beneficiation at the mining site or at an intermediate processing facility prior to being transported to the ceramic manufacturing facility.

Comminution entails reducing the particle size of the raw material by crushing, grinding, and milling or fine grinding. The purpose of comminution is to liberate impurities, break up aggregates, modify particle morphology and size distribution, facilitate mixing and forming, and produce a more reactive material for firing. Primary crushing generally reduces material up to 0.3 meter (m) (1 foot [ft]) in diameter down to 1 centimeter (cm) (0.40 inch [in.]) in diameter. Secondary crushing reduces particle size down to approximately 1 millimeter (mm) (0.04 in.) in diameter. Fine grinding or milling reduces the particle size down to as low as 1.0 micrometer (μ m) (4 x 10⁻⁵ in.) in diameter. Ball mills are the most commonly used piece of equipment for milling. However, vibratory mills, attrition mills, and fluid energy mills also are used. Crushing and grinding typically are dry processes; milling may be a wet or dry process. In wet milling, water or alcohol commonly is used as the milling liquid.

Several procedures are used to purify the ceramic material. Water soluble impurities can be removed by washing with deionized or distilled water and filtering, and organic solvents may be used for removing water-insoluble impurities. Acid leaching sometimes is employed to remove metal contaminants. Magnetic separation is used to extract magnetic impurities from either dry powders or wet slurries. Froth flotation also is used to separate undesirable materials.

Sizing and classification separate the material into size ranges. Sizing is most often accomplished using fixed or vibrating screens. Dry screening can be used to sizes down to 44 μ m (0.0017 in., 325 mesh). Dry forced-air sieving and sonic sizing can be used to size dry powders down to 37 μ m (0.0015 in., 400 mesh), and wet sieving can be used for particles down to 25 μ m (0.00098 in., 500 mesh). Air classifiers generally are effective in the range of 420 μ m to 37 μ m

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Figure 11.7-1. Process flow diagram for ceramic products manufacturing. (Source Classification Codes in parentheses.)

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(0.017 to 0.0015 in., 40 to 400 mesh). However, special air classifiers are available for isolating particles down to 10 μ m (0.00039 in.).

Calcining consists of heating a ceramic material to a temperature well below its melting point to liberate undesirable gases or other material and to bring about structural transformation to produce the desired composition and phase product. Calcining typically is carried out in rotary calciners, heated fluidized beds, or by heating a static bed of ceramic powder in a refractory crucible.

Liquid dispersion of ceramic powders sometimes is used to make slurries. Slurry processing facilitates mixing and minimizes particle agglomeration. The primary disadvantage of slurry processing is that the liquid must be removed prior to firing the ceramic.

Dry powders often are granulated to improve flow, handling, packing, and compaction. Granulation is accomplished by direct mixing, which consists of introducing a binder solution during powder mixing, or by spray drying. Spray dryers generally are gas-fired and operate at temperatures of 110° to 130° C (230° to 270°F).

11.7.2.3 Mixing -

The purpose of mixing or blunging is to combine the constituents of a ceramic powder to produce a more chemically and physically homogenous material for forming. Pug mills often are used for mixing ceramic materials. Several processing aids may be added to the ceramic mix during the mixing stage. Binders and plasticizers are used in dry powder and plastic forming; in slurry processing, deflocculants, surfactants, and antifoaming agents are added to improve processing. Liquids also are added in plastic and slurry processing.

Binders are polymers or colloids that are used to impart strength to green or unfired ceramic bodies. For dry forming and extrusion, binders amount to 3 percent by weight of the ceramic mixture. Plasticizers and lubricants are used with some types of binders. Plasticizers increase the flexibility of the ceramic mix. Lubricants lower frictional forces between particles and reduce wear on equipment. Water is the most commonly used liquid in plastic and slurry processing. Organic liquids such as alcohols may also be used in some cases. Deflocculants also are used in slurry processing to improve dispersion and dispersion stability. Surfactants are used in slurry processing to aid dispersion, and antifoams are used to remove trapped gas bubbles from the slurry.

11.7.2.4 Forming -

In the forming step, dry powders, plastic bodies, pastes, or slurries are consolidated and molded to produce a cohesive body of the desired shape and size. Dry forming consists of the simultaneous compacting and shaping of dry ceramic powders in a rigid die or flexible mold. Dry forming can be accomplished by dry pressing, isostatic compaction, and vibratory compaction.

Plastic molding is accomplished by extrusion, jiggering, or powder injection molding. Extrusion is used in manufacturing structural clay products and some refractory products. Jiggering is widely used in the manufacture of small, simple, axially symmetrical whiteware ceramic such as cookware, fine china, and electrical porcelain. Powder injection molding is used for making small complex shapes.

Paste forming consists of applying a thick film of ceramic paste on a substrate. Ceramic pastes are used for decorating ceramic tableware, and forming capacitors and dielectric layers on rigid substrates for microelectronics.

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Slurry forming of ceramics generally is accomplished using slip casting, gelcasting, or tape casting. In slip casting, a ceramic slurry, which has a moisture content of 20 to 35 percent, is poured into a porous mold. Capillary suction of the mold draws the liquid from the mold, thereby consolidating the cast ceramic material. After a fixed time the excess slurry is drained, and the cast is dried. Slip casting is widely used in the manufacture of sinks and other sanitaryware, figurines, porous thermal insulation, fine china, and structural ceramics with complex shapes. Gelcasting uses in situ polymerization of organic monomers to produce a gel that binds ceramic particles together into complex shapes such as turbine rotors. Tape casting consists of forming a thin film of ceramic slurry of controlled thickness onto a support surface using a knife edge. Tape casting is used to produce thin ceramic sheets or tape, which can be cut and stacked to form multilayer ceramics for capacitors and dielectric insulator substrates.

11.7.2.5 Green Machining -

After forming, the ceramic shape often is machined to eliminate rough surfaces and seams or to modify the shape. The methods used to machine green ceramics include surface grinding to smooth surfaces, blanking and punching to cut the shape and create holes or cavities, and laminating for multilayer ceramics.

11.7.2.6 Drying -

After forming, ceramics must be dried. Drying must be carefully controlled to strike a balance between minimizing drying time and avoiding differential shrinkage, warping, and distortion. The most commonly used method of drying ceramics is by convection, in which heated air is circulated around the ceramics. Air drying often is performed in tunnel kilns, which typically use heat recovered from the cooling zone of the kiln. Periodic kilns or dryers operating in batch mode also are used. Convection drying also is carried out in divided tunnel dryers, which include separate sections with independent temperature and humidity controls. An alternative to air drying is radiation drying in which microwave or infrared radiation is used to enhance drying.

11.7.2.7 Presinter Thermal Processing -

Prior to firing, ceramics often are heat-treated at temperatures well below firing temperatures. The purpose of this thermal processing is to provide additional drying, to vaporize or decompose organic additives and other impurities, and to remove residual, crystalline, and chemically bound water. Presinter thermal processing can be applied as a separate step, which is referred to as bisque firing, or by gradually raising and holding the temperature in several stages.

11.7.2.8 Glazing -

For traditional ceramics, glaze coatings often are applied to dried or bisque-fired ceramic ware prior to sintering. Glazes consist primarily of oxides and can be classified as raw glazes or frit glazes. In raw glazes, the oxides are in the form of minerals or compounds that melt readily and act as solvents for the other ingredients. Some of the more commonly used raw materials for glazes are quartz, feldspars, carbonates, borates, and zircon. A frit is a prereacted glass. Frit manufacturing is addressed in AP-42 Section 11.14.

To prepare glazes, the raw materials are ground in a ball mill or attrition mill. Glazes generally are applied by spraying or dipping. Depending on their constituents, glazes mature at temperatures of 600° to 1500° C (1110° to 2730° F).

11.7.2.9 Firing -

Firing is the process by which ceramics are thermally consolidated into a dense, cohesive body comprised of fine, uniform grains. This process also is referred to as sintering or densification. In

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general: (1) ceramics with fine particle size fire quickly and require lower firing temperatures;
(2) dense unfired ceramics fire quickly and remain dense after firing with lower shrinkage; and
(3) irregular shaped ceramics fire quickly. Other material properties that affect firing include material surface energy, diffusion coefficients, fluid viscosity, and bond strength.

Parameters that affect firing include firing temperature, time, pressure, and atmosphere. A short firing time results in a product that is porous and has a low density; a short to intermediate firing time results in fine-grained (i. e., having particles not larger than 0.2 millimeters), high-strength products; and long firing times result in a coarse-grained products that are more creep resistant. Applying pressure decreases firing time and makes it possible to fire materials that are difficult to fire using conventional methods. Oxidizing or inert atmospheres are used to fire oxide ceramics to avoid reducing transition metals and degrading the finish of the product.

In addition to conventional firing, other methods used include pressure firing, hot forging, plasma firing, microwave firing, and infrared firing. The following paragraphs describe conventional and pressure firing, which are the methods used often.

Conventional firing is accomplished by heating the green ceramic to approximately two-thirds of the melting point of the material at ambient pressure and holding it for a specified time in a periodic or tunnel kiln. Periodic kilns are heated and cooled according to prescribed schedules. The heat for periodic kilns generally is provided by electrical element or by firing with gas or oil.

Tunnel kilns generally have separate zones for cooling, firing, and preheating or drying. The kilns may be designed so that (1) the air heated in the cooling zone moves into the firing zone and the combustion gases in the firing zone are conveyed to the preheat/drying zone then exhausted, or (2) the air heated in the cooling zone is conveyed to the preheat/drying zone and the firing zone gases are exhausted separately. The most commonly used tunnel kiln design is the roller hearth (roller) kiln. In conventional firing, tunnel kilns generally are fired with gas, oil, coal, or wood. Following firing and cooling, ceramics are sometimes refired after the application of decals, paint, or ink.

Advanced ceramics often are fired in electric resistance-heated furnaces with controlled atmospheres. For some products, separate furnaces may be needed to eliminate organic lubricants and binders prior to firing.

Ceramic products also are manufactured by pressure firing, which is similar to the forming process of dry pressing except that the pressing is conducted at the firing temperature. Because of its higher costs, pressure firing is usually reserved for manufacturing ceramics that are difficult to fire to high density by conventional firing.

11.7.2.10 Final Processing -

Following firing, some ceramic products are processed further to enhance their characteristics or to meet dimensional tolerances. Ceramics can be machined by abrasive grinding, chemical polishing, electrical discharge machining, or laser machining. Annealing at high temperature, followed by gradual cooling can relieve internal stresses within the ceramic and surface stresses due to machining. In addition, surface coatings are applied to many fired ceramics. Surface coatings are applied to traditional clay ceramics to create a stronger, impermeable surface and for decoration. Coatings also may be applied to improve strength, and resistance to abrasion and corrosion. Coatings can be applied dry, as slurries, by spraying, or by vapor deposition.

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11.7.3 Emissions And Controls^{1,3,5,12-31}

The primary pollutants associated with raw material beneficiation are particulate matter (PM) and PM less than 10 μ m in aerodynamic diameter (PM-10). Filterable PM and PM-10 are emitted from comminution, sizing, classifying, handling, transfer, and storage. In addition, raw material calciners emit filterable and condensible PM, which may include metals and other inorganic pollutants. Calciners also emit products of combustion such as nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), carbon dioxide (CO₂), and volatile organic compounds (VOC). Emissions of SO_x are a function of the sulfur content of the fuel used to fire the calciners and the sulfur content of the raw materials used to manufacture ceramics. Emissions of VOC result from incomplete combustion and volatilization of the organic material associated with the raw material. Other beneficiation processes that are associated with emissions include acid leaching and granulation. Emissions of hydrochloric acid (HCl) or other acids may arise from leaching. In addition, PM and products of combustion are emitted from spray dryers used for granulation.

Mixing generally is a wet process. However, VOC emissions from this step may arise from the volatilization of binders, plasticizers, and lubricants. Forming generally is performed in sealed containers and often is a wet process; emissions from this step in the process are likely to be negligible. However, tape casters are a source of VOC emissions. For ceramic bodies that are dryformed, PM is likely to be emitted from grinding, punching, and other green machining activities.

Particulate matter emissions consisting of metal and mineral oxides also arise from glaze preparation, which includes mixing and grinding. Emissions of PM from glaze application also are likely, if the glaze is applied by spraying.

Emissions associated from green ceramic heat treating processes, which include drying, presinter thermal processing, and firing, include combustion products and filterable and condensible PM. Particulate matter emissions consist in part of metals and the inorganic minerals associated with the raw materials. Emissions of the products of combustion are a function of fuel type, raw material constituents, process temperature, and other operating parameters.

Emissions of fluorine compounds also are associated with firing. Fluorine is present in ceramic raw materials in the range of 0.01 to 0.2 percent. As the temperature of green ceramic bodies reaches 500° to 600° C (930° to 1110° F), the fluorine in the raw material forms hydrogen fluoride (HF) and other fluorine compounds such as silicon tetrafluoride. Much of the fluorine is released as HF. However, if lime is present in the ceramic body, HF reacts with the lime to form calcium fluoride (CaF₂), thereby reducing potential HF emissions.

Other emission sources associated with ceramics manufacturing include final processing operations and fugitive dust sources. The final processing steps include grinding and polishing, which can emit PM and PM-10, and surface coating, annealing, and chemical treatment, which can emit VOC. Fugitive dust sources, which consist of vehicular traffic, wind erosion of storage piles, and materials handling and transfer, emit PM and PM-10.

Several techniques have been used to control PM emissions from the mechanical processing of ceramic raw materials and finished products. Fabric filters are the most commonly used control device, but wet scrubbers and electrostatic precipitators (ESPs) also are used. Fabric filters, wet scrubbers, and ESPs also are used to control emissions from clay calciners and dryers. Venturi scrubbers and fabric filters are used to control emissions from granulation (spray dryers) and from

glaze preparation and application. Afterburners have been used to control VOC emissions from tape casting operations. Emissions from kilns generally are uncontrolled.

Emissions of HF from kilns can be reduced through process modifications such as increasing the raw material lime content and reducing kiln draft, kiln exhaust temperature, and kiln residence time. Dry sorption scrubbing also has been used to control HF emissions in the brick and ceramic industries in Germany and in the brick industry in the United States. These devices use limestone as a sorption medium to produce CaF_2 , which is removed by means of a rotating screen, drum, or fabric filter. Control efficiencies of 95 to 99 percent have been reported for this type of scrubber.

Table 11.7-1 presents emission factors for PM and lead emissions from various ceramic products manufacturing processes. Table 11.7.2 present emission factors for SO_2 , NO_x , CO, CO_2 , VOC, HF, and fluoride emissions from ceramic kilns and tape casters.

Source	Filterable PM (lb/ton) ^b	EMISSION FACTOR RATING	Lead (lb/ton)	EMISSION FACTOR RATING
Comminutionraw material crushing and screening line with fabric filter ^c (SCC 3-05-008-02)	0.12	D	ND	NA
Dryer ^d (SCC 3-05-008-13)	2.3	Е	ND	NA
Cooler ^d (SCC 3-05-008-58)	0.11	E	ND	NA
Granulationnatural gas-fired spray dryer (SCC 3-05-008-10)				
with fabric filter ^e with venturi scrubber ^f	0.060 0.19	E D	ND ND	NA NA
Firingnatural gas-fired kiln ^g (SCC 3-05-008-50)	0.49	D	ND	NA
Refiringnatural gas-fired kiln ^h (SCC 3-05-008-56)	0.067	Е	ND	NA
Ceramic glaze spray booth (SCC 3-05-008-45)				
uncontrolled ¹ with wet scrubber ^k	19 1.8	E D	3.0 ND	E NA

Table 11.7-1. EMISSION FACTORS FOR CERAMIC PRODUCTS MANUFACTURING OPERATIONS^a

^a Emission factor units are lb of pollutant per ton of fired ceramic produced, unless noted. To convert from lb/ton to kg/Mg, multiply by 0.5. Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Filterable PM is that PM collected on the front-half of an EPA Method 5 (or equivalent) sampling train. Although condensible organic and inorganic PM emissions are expected from dryers and kilns, no data are available to estimate these emissions.

^c References 12-13. Raw material processing for production of quarry tile, which is an unglazed tile product similar to structural clay products. Emission factor units are lb of pollutant per ton of material processed.

^e Reference 16. Emission factor units are lb of pollutant per ton of dry material produced.

^f References 26-29. Emission factor units are lb of pollutant per ton of dry material produced.

^g References 7,9-11,15,23-25.

^h Reference 6. Kiln is used for refiring tile after application of decals, paint, or ink screening.

^J Reference 30. Emission factor units are lb of pollutant per ton of glazed used. Glaze contains about 24 percent lead oxide.

^k References 20-22. Emission factor units are lb of pollutant per ton of glaze used.

^d Reference 15.

Table 11.7-2. EMISSION FACTORS FOR GASEOUS POLLUTANT EMISSIONS FROM
CERAMIC PRODUCTS MANUFACTURING^a

Source	SO ₂	NO _x	СО	CO ₂	VOC ^b	HF ^c	Fluorides ^d
Firingnatural gas-fired kiln (SCC 3-05-008-50)	44·S ^e	0.54 ^f	3.3 ^g	780 ^f	0.43 ^g	0.46 ^h	0.56 ^j
Refiringnatural gas-fired kiln ^k (SCC 3-05-008-56)	ND	ND	ND	97	ND	ND	0.019
Formingtape casters ^m (SCC 3-05-008-31)	ND	ND	ND	ND	58	ND	ND

EMISSION FACTOR RATING: E

^a Emission factor units are lb of pollutant per ton of ceramic product produced, unless noted. To convert from lb/ton to kg/Mg, multiply by 0.5. Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data.

^b VOC reported on an "as propane" basis; measured using EPA Method 25A. Emission factor may include nonphotochemically reactive compounds that are not considered VOC. No data are available to estimate emissions of these non-VOC compounds.

^c Hydrogen fluoride measured using EPA Method 26A. This compound is listed as a hazardous air pollutant under Section 112(b) of the Clean Air Act, as amended in November 1990. A mass balance on flouride will provide a better estimate of HF emissions for individual facilities.

^d Total fluorides measured during EPA Method 13A or 13B. Measurements include HF and other fluorine compounds. A mass balance on flouride will provide a better estimate of fluoride emissions for individual facilities.

^e Reference 10. For facilities using raw material with a sulfur content greater than 0.07 percent. The variable S represents the raw material sulfur content (percent). For facilities using raw material with a sulfur content less than or equal to 0.07 percent, use 9.5 S lb/ton to estimate emissions (References 9,11). Emissions of SO₂ are dependent on the sulfur content of the raw material and the fuel used to fire the kiln.

- ^f References 9,11,15. EMISSION FACTOR RATING: D.
- ^g Reference 15. EMISSION FACTOR RATING: D.
- ^h Reference 15.
- ^j References 7,9-11, 23-25.

^m Reference 14. Emission factor units are lb of pollutant per ton of formed product. Emissions controlled by an afterburner.

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11.8 Clay And Fly Ash Sintering

NOTE: Clay and fly ash sintering operations are no longer conducted in the United States. However, this section is being retained for historical purposes.

11.8.1 Process Description¹⁻³

Although the process for sintering fly ash and clay are similar, there are some distinctions that justify a separate discussion of each process. Fly ash sintering plants are generally located near the source, with the fly ash delivered to a storage silo at the plant. The dry fly ash is moistened with a water solution of lignin and agglomerated into pellets or balls. This material goes to a traveling-grate sintering machine where direct contact with hot combustion gases sinters the individual particles of the pellet and completely burns off the residual carbon in the fly ash. The product is then crushed, screened, graded, and stored in yard piles.

Clay sintering involves the driving off of entrained volatile matter. It is desirable that the clay contain a sufficient amount of volatile matter so that the resultant aggregate will not be too heavy. It is thus sometimes necessary to mix the clay with finely pulverized coke (up to 10 percent coke by weight). In the sintering process, the clay is first mixed with pulverized coke, if necessary, and then pelletized. The clay is next sintered in a rotating kiln or on a traveling grate. The sintered pellets are then crushed, screened, and stored, in a procedure similar to that for fly ash pellets.

11.8.2 Emissions And Controls¹

In fly ash sintering, improper handling of the fly ash creates a dust problem. Adequate design features, including fly ash wetting systems and particulate collection systems on all transfer points and on crushing and screening operations, would greatly reduce emissions. Normally, fabric filters are used to control emissions from the storage silo, and emissions are low. The absence of this dust collection system, however, would create a major emission problem. Moisture is added at the point of discharge from silo to the agglomerator, and very few emissions occur there. Normally, there are few emissions from the sintering machine, but if the grate is not properly maintained, a dust problem is created. The consequent crushing, screening, handling, and storage of the sintered product also create dust problems.

In clay sintering, the addition of pulverized coke presents an emission problem because the sintering of coke-impregnated dry pellets produces more particulate emissions than the sintering of natural clay. The crushing, screening, handling, and storage of the sintered clay pellets creates dust problems similar to those encountered in fly-ash sintering. Emission factors for both clay and fly-ash sintering are shown in Tables 11.8-1 and 11.8-2.

Table 11.8-1 (Metric Units). EMISSION FACTORS FOR CLAY AND FLY ASH SINTERING^a

		Filterable ^b				Condensable PM ^c			
	РМ		PM-10		Inorganic		Organic		
Source (SCC)	kg/Mg EMISSION Of FACTOR Material RATING M		kg/Mg Of Material	EMISSION FACTOR RATING	kg/Mg Of Material	EMISSION FACTOR RATING	kg/Mg Of Material	EMISSION FACTOR RATING	
Fly ash crushing, screening, sintering, and storage (3-05-009-01) ^d	55	E	ND		ND		ND		
Clay/coke mixture sintering (3-05-009-02) ^e	20	Ε	ND		ND		ND		
Clay/coke mixture crushing, screening, and storage (3-05-009-07) ^f	7.5	E	ND		ND		ND		
Natural clay sintering (3-05-009-03) ^g	6	Е	ND		ND		ND		
Natural clay crushing, screening, and storage (3-05-009-04) ^f	6	E	ND		ND		ND		

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data. ^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d Reference 1.

^e References 3-5; for 90% clay, 10% pulverized coke; traveling grate, single pass, up-draft sintering machine.
 ^f Based on data in Section 11.19-2.

^g Reference 2; rotary dryer sinterer.

		Filterable ^b				Condensable PM ^c			
	РМ		PM-10		Inorganic		Organic		
Source (SCC)	lb/ton Of Material	EMISSION FACTOR RATING	lb/ton Of Material	EMISSION FACTOR RATING	lb/ton Of Material	EMISSION FACTOR RATING	lb/ton Of Material	EMISSION FACTOR RATING	
Fly ash crushing, screening, sintering, and storage (3-05-009-01) ^d	110	E	ND		ND		ND		
Clay/coke mixture sintering (3-05-009-02) ^e	40	Ε	ND		ND		ND		
Clay/coke mixture crushing, screening, and storage (3-05-009-07) ^f	15	Е	ND		ND		ND		
Natural clay sintering (3-05-009-03) ^g	12	Ε	ND		ND		ND		
Natural clay crushing, screening, and storage (3-05-009-04) ^f	12	E	ND		ND		ND		

Table 11.8-2 (English Units). EMISSION FACTORS FOR CLAY AND FLY ASH SINTERING^a

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data.
 ^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.
 ^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d Reference 1.

^e References 3-5; for 90% clay, 10% pulverized coke; traveling grate, single pass, up-draft sintering machine.
 ^f Based on data in Section 11.19-2.

^g Reference 2; rotary dryer sinterer.

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11.9 Western Surface Coal Mining

11.9 General¹

There are 12 major coal fields in the western states (excluding the Pacific Coast and Alaskan fields), as shown in Figure 11.9-1. Together, they account for more than 64 percent of the surface minable coal reserves in the United States.² The 12 coal fields have varying characteristics that may influence fugitive dust emission rates from mining operations including overburden and coal seam thicknesses and structure, mining equipment, operating procedures, terrain, vegetation, precipitation and surface moisture, wind speeds, and temperatures. The operations at a typical western surface mine are shown in Figure 11.9-2. All operations that involve movement of soil, coal, or equipment, or exposure of erodible surfaces, generate some amount of fugitive dust.

The initial operation is removal of topsoil and subsoil with large scrapers. The topsoil is carried by the scrapers to cover a previously mined and regraded area as part of the reclamation process or is placed in temporary stockpiles. The exposed overburden, the earth that is between the topsoil and the coal seam, is leveled, drilled, and blasted. Then the overburden material is removed down to the coal seam, usually by a dragline or a shovel and truck operation. It is placed in the adjacent mined cut, forming a spoils pile. The uncovered coal seam is then drilled and blasted. A shovel or front end loader loads the broken coal into haul trucks, and it is taken out of the pit along graded haul roads to the tipple, or truck dump. Raw coal sometimes may be dumped onto a temporary storage pile and later rehandled by a front end loader or bulldozer.

At the tipple, the coal is dumped into a hopper that feeds the primary crusher, then is conveyed through additional coal preparation equipment such as secondary crushers and screens to the storage area. If the mine has open storage piles, the crushed coal passes through a coal stacker onto the pile. The piles, usually worked by bulldozers, are subject to wind erosion. From the storage area, the coal is conveyed to a train loading facility and is put into rail cars. At a captive mine, coal will go from the storage pile to the power plant.

During mine reclamation, which proceeds continuously throughout the life of the mine, overburden spoils piles are smoothed and contoured by bulldozers. Topsoil is placed on the graded spoils, and the land is prepared for revegetation by furrowing, mulching, etc. From the time an area is disturbed until the new vegetation emerges, all disturbed areas are subject to wind erosion.

11.9 Emissions

Predictive emission factor equations for open dust sources at western surface coal mines are presented in Tables 11.9-1 and 11.9-2. Each equation is for a single dust-generating activity, such as vehicle traffic on unpaved roads. The predictive equation explains much of the observed variance in emission factors by relating emissions to 3 sets of source parameters: (1) measures of source activity or energy expended (e. g., speed and weight of a vehicle traveling on an unpaved road); (2) properties of the material being disturbed (e. g., suspendable fines in the surface material of an unpaved road); and (3) climate (in this case, mean wind speed).

The equations may be used to estimate particulate emissions generated per unit of source extent (e. g., vehicle distance traveled or mass of material transferred). The equations were



Figure 11.9-1. Coal fields of the western United States.



Figure 11.9-2. Operations at typical western surface coal mines.

		Emissions By		EMISSION			
Operation	Material	TSP ≤ 30 μm	≤15 µm	$\leq 10 \ \mu m^d$	≤2.5 μm/TSP ^c	Units	RATING
Blasting	Coal or overburden	0.00022 ^{1.5}	ND	0.52 ^e	ND	kg/blast	С
Truck loading	Coal	$\frac{0.580}{(M)^{1.2}}$	<u>0.0596</u> (M) ^{0.9}	0.75	0.019	kg/Mg	В
Bulldozing	Coal	$\frac{35.6 \text{ (s)}^{1.2}}{(\text{M})^{1.4}}$	$\frac{8.44 (s)^{1.5}}{(M)^{1.4}}$	0.75	0.022	kg/hr	В
	Overburden	$\frac{2.6 \text{ (s)}^{1.2}}{(\text{M})^{1.3}}$	$\frac{0.45 \text{ (s)}^{1.5}}{(\text{M})^{1.4}}$	0.75	0.105	kg/hr	В
Dragline	Overburden	$\frac{0.0046 \ (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0029 \ (d)^{0.7}}{(M)^{0.3}}$	0.75	0.017	kg/m ³	В
Scraper (travel mode)		9.6 x 10^{-6} (s) ^{1.3} (W) ^{2.4}	2.2 x 10^{-6} (s) ^{1.4} (W) ^{2.5}	0.60	0.026	kg/VKT	A
Grading		0.0034 (S) ^{2.5}	0.0056 (S) ^{2.0}	0.60	0.031	kg/VKT	В
Vehicle traffic (light/medium duty)		$\frac{1.63}{(M)^{4.0}}$	$\frac{1.05}{(M)^{4.3}}$	0.60	0.040	kg/VKT	В
Haul truck		$0.0019 (w)^{3.4} (L)^{0.2}$	$0.0014 (w)^{3.5}$	0.60	0.017	kg/VKT	A
Active storage pile (wind erosion and maintenance)	Coal	1.8 u	ND	ND	ND	kg (hectare)(hr)	Cf

Table 11.9-1 (Metric Units). EMISSION FACTOR EQUATIONS FOR UNCONTROLLED OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES^a

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^a Reference 1, except for coal storage pile equation from Reference 4. TSP = total suspended particulate. VKT = vehicle kilometerstraveled. ND = no data.
^b TSP denotes what is measured by a standard high volume sampler (see Section 13.2).
^c Symbols for equations:

A = horizontal area, with blasting depth ≤ 21 m. Not for vertical face of a bench. M = material moisture content (%)

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- s = material silt content (%)
- u = wind speed (m/sec)
- d = drop height (m)
- W = mean vehicle weight (Mg)
- S = mean vehicle speed (kph)
- w = mean number of wheels

- L = road surface silt loading (g/m^2) ^d Multiply the $\leq 15 \ \mu m$ equation by this fraction to determine emissions. ^e Multiply the TSP predictive equation by this fraction to determine emissions in the $\leq 2.5 \ \mu m$ size range. ^f Rating applicable to Mine Types I, II, and IV (see Tables 11.9-5 and 11.9-6).

		Emissions By Particle Size Range (Aerodymanic Diameter) ^{b,c}					EMISSION
Operation	Material	TSP \leq 30 μ m	≤15 µm	≤10 µm ^d	≤2.5 μm/TSP ^c	Units	FACTOR RATING
Blasting	Coal or overburden	0.0005A ^{1.5}	ND	0.52 ^e	ND	lb/blast	с
Truck loading	Coal	$\frac{1.16}{(M)^{1.2}}$	$\frac{0.119}{(M)^{0.9}}$	0.75	0.019	lb/ton	В
Bulldozing	Coal	$\frac{78.4 \text{ (s)}^{1.2}}{(\text{M})^{1.3}}$	$\frac{18.6 (s)^{1.5}}{(M)^{1.4}}$	0.75	0.022	lb/ton	В
	Overburden	$\frac{5.7 \text{ (s)}^{1.2}}{(\text{M})^{1.3}}$	$\frac{1.0 (c)^{1.5}}{(M)^{1.4}}$	0.75	0.105	lb/ton	В
Dragline	Overburden	$\frac{0.0021 (d)^{1.1}}{(M)^{0.3}}$	$\frac{0.0021 \text{ (d)}^{0.7}}{(\text{M})^{0.3}}$	0.75	0.017	lb/yd ³	В
Scraper (travel mode)		2.7 x 10^{-5} (s) ^{1.3} (W) ^{2.4}	6.2 x 10^{-6} (s) ^{1.4} (W) ^{2.5}	0.60	0.026	ib/VMT	A
Grading		0.040 (S) ^{2.5}	0.051 (S) ^{2.0}	0.60	0.031	lb/VMT	В
Vehicle traffic (light/medium duty)		<u>5.79</u> (M) ^{4.0}	$\frac{3.72}{(M)^{4.3}}$	0.60	0.040	ib/VMT	В
Haul truck		$0.0067 (w)^{3.4} (L)^{0.2}$	0.0051 (w) ^{3.5}	0.60	0.017	lb/VMT	A
Active storage pile (wind erosion and maintenance)	Coal	1.6 u	ND	ND	ND	<u>lb</u> (acre)(hr)	Ct

Table 11.9-2 (English Units). EMISSION FACTOR EQUATIONS FOR UNCONTROLLED OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES^a

^a Reference 1, except for coal storage pile equation from Reference 4. TSP = total suspended particulate. VMT = vehicle miles traveled.ND = no data.
^b TSP denotes what is measured by a standard high volume sampler (see Section 13.2).
^c Symbols for equations: A = horizontal area, with blasting depth ≤70 ft. Not for vertical face of a bench. M = material moisture content (%)

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- s = material silt content (%)
- u = wind speed (m/sec)
- d = drop height (ft)
- W = mean vehicle weight (tons)
- S = mean vehicle speed (mph)
- w = mean number of wheels

- L = road surface silt loading (g/m^2) ^d Multiply the $\leq 15 \ \mu m$ equation by this fraction to determine emissions. ^e Multiply the TSP predictive equation by this fraction to determine emissions in the $\leq 2.5 \ \mu m$ size range. ^f Rating applicable to Mine Types I, II, and IV (see Tables 11.9-5 and 11.9-6).

developed through field sampling of various western surface mine types and are thus applicable to any of the surface coal mines located in the western United States.

In Tables 11.9-1 and 11.9-2, the assigned quality ratings apply within the ranges of source conditions that were tested in developing the equations given in Table 11.9-3. However, the equations should be derated 1 letter value (e. g., A to B) if applied to eastern surface coal mines.

In using the equations to estimate emissions from sources found in a specific western surface mine, it is necessary that reliable values for correction parameters be determined for the specific sources of interest if the assigned quality ranges of the equations are to be applicable. For example, actual silt content of coal or overburden measured at a facility should be used instead of estimated values. In the event that site-specific values for correction parameters cannot be obtained, the appropriate geometric mean values from Table 11.9-3 may be used, but the assigned quality rating of each emission factor equation should be reduced by 1 level (e. g., A to B).

Emission factors for open dust sources not covered in Table 11.9-3 are in Table 11.9-4. These factors were determined through source testing at various western coal mines.

_		Number Of Test	-	Geometric	
Source	Correction Factor	Samples	Range	Mean	Units
Coal loading	Moisture	7	6.6 - 38	17.8	%
Bulldozers					
Coal	Moisture	3	4.0 - 22.0	10.4	%
	Silt	3	6.0 - 11.3	8.6	%
Overburden	Moisture	8	2.2 - 16.8	7.9	%
	Silt	8	3.8 - 15.1	6.9	%
Dragline	Drop distance	19	1.5 - 30	8.6	m
	Drop distance	19	5 - 100	28.1	ft
	Moisture	7	0.2 - 16.3	3.2	%
Scraper	Silt	10	7.2 - 25.2	16.4	%
	Weight	15	33 - 64	48.8	Mg
	Weight	15	36 - 70	53.8	ton
Grader	Speed	7	8.0 - 19.0	11.4	kph
	Speed		5.0 - 11.8	7.1	mph
Light/Medium duty vehicle	Moisture	7	0.9 - 1.70	1.2	%
Haul truck	Wheels	29	6.1 - 10.0	8.1	number
	Silt loading	26	3.8 - 254	40.8	g/m ²
	Silt loading	26	34 - 2270	364	lb/acre

Table 11.9-3 (Metric And English Units).	TYPICAL VALUES FOR CORRECTION FACTORS
APPLICABLE TO THE PREDI	CTIVE EMISSION FACTOR EQUATIONS ^a

^a Reference 1.

Source	Material	Mine Location ^a	TSP Emission Factor ^b	Units	EMISSION FACTOR RATING
Drilling	Overburden	Any	1.3 0.59	lb/hole kg/hole	B B
	Coal	v	0.22 0.10	lb/hole kg/hole	E E
Topsoil removal by scraper	Topsoil	Any	0.058 0.029	lb/ton kg/Mg	E E
		IV	0.44 0.22	lb/ton kg/Mg	D D
Overburden replacement	Overburden	Any	0.012 0.0060	lb/ton kg/Mg	C C
Truck loading by power shovel (batch drop) ^c	Overburden	. v	0.037 0.018	lb/ton kg/Mg	C C
Train loading (batch or continuous drop) ^c	Coal	Any	0.028 0.014	lb/ton kg/Mg	D D
		111	0.0002 0.0001	lb/ton kg/Mg	D D
Bottom dump truck unloading (batch drop) ^c	Overburden	v	0.002 0.001	lb/ton kg/ton	E E
	Coal	IV	0.027 0.014	lb/ton kg/Mg	E E
		III	0.005 0.002	lb/ton kg/Mg	E E
		II	0.020 0.010	lb/ton kg/Mg	E E

Table 11.9-4 (English And Metric Units). UNCONTROLLED PARTICULATE EMISSION FACTORS FOR OPEN DUST SOURCES AT WESTERN SURFACE COAL MINES

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Source	Material	Mine Location ^a	TSP Emission Factor ^b	Units	EMISSION FACTOR RATING
		I	0.014 0.0070	lb/T kg/Mg	D D
		Any	0.066 0.033	lb/T kg/Mg	D D
End dump truck unloading (batch drop) ^c	Coal	V	0.007 0.004	lb/T kg/Mg	E E
Scraper unloading (batch drop) ^c	Topsoil	IV	0.04 0.02	lb/T kg/Mg	с с
Wind erosion of exposed areas	Seeded land, stripped overburden, graded overburden	Any	0.38	<u> </u>	с
			0.85	<u>Mg</u> (hectare)(yr)	с

Table 11.9-4 (cont.).

^a Roman numerals I through V refer to specific mine locations for which the corresponding emission factors were developed.

Tables 11.9-4 and 11.9-5 present characteristics of each of these mines. See text for correct use of these "mine-specific" emission factors. The other factors (from Reference 5 except for overburden drilling from Reference 1) can be applied to any western surface coal mine.

^b Total suspended particulate (TSP) denotes what is measured by a standard high volume sampler (see Section 13.2).

^c Predictive emission factor equations, which generally provide more accurate estimates of emissions, are presented is Chapter 13.

The factors in Table 11.9-4 for mine locations I through V were developed for specific geographical areas. Tables 11.9-5 and 11.9-6 present characteristics of each of these mines (areas). A "mine-specific" emission factor should be used only if the characteristics of the mine for which an emissions estimate is needed are very similar to those of the mine for which the emission factor was developed. The other (nonspecific) emission factors were developed at a variety of mine types and thus are applicable to any western surface coal mine.

As an alternative to the single valued emission factors given in Table 11.9-4 for train or truck loading and for truck or scraper unloading, 2 empirically derived emission factor equations are presented in Section 13.2.4 of this document. Each equation was developed for a source operation (i. e., batch drop and continuous drop, respectively) comprising a single dust-generating mechanism that crosses industry lines.

Because the predictive equations allow emission factor adjustment to specific source conditions, the equations should be used in place of the factors in Table 11.9-4 for the sources identified above if emission estimates for a specific western surface coal mine are needed. However, the generally higher quality ratings assigned to the equations are applicable only if: (1) reliable values of correction parameters have been determined for the specific sources of interest, and (2) the correction parameter values lie within the ranges tested in developing the equations. Table 11.9-3 lists measured properties of aggregate materials that can be used to estimate correction parameter values for the predictive emission factor equations in Chapter 13, in the event that site-specific values are not available. Use of mean correction parameter values from Table 11.9-3 will reduce the quality ratings of the emission factor equations in Chapter 13 by 1 level.

					Surface Soil Type	Mean Wind Speed		Mean Annual Precipitation	
Mine	Location	Type Of Coal Mined	Terrain	Cover	And Erodibility Index	m/s	mph	cm	in.
I	N.W. Colorado	Subbitum.	Moderately steep	Moderate, sagebrush	Clayey loamy (71)	2.3	5.1	38	15
П	S.W. Wyoming	Subbitum.	Semirugged	Sparse, sagebrush	Arid soil with clay and alkali or carbonate accumulation (86)	6.0	13.4	36	14
ш	S.E. Montana	Subbitum.	Gently rolling to semirugged	Sparse, moderate, prairie grassland	Shallow clay loamy deposits on bedrock (47)	4.8	10.7	28 - 41	11 - 16
IV	Central North Dakota	Lignite	Gently rolling	Moderate, prairie grassland	Loamy, loamy to sandy (71)	5.0	11.2	43	17
v	N.E. Wyoming	Subbitum.	Flat to gently rolling	Sparse, sagebrush	Loamy, sandy, clayey, and clay loamy (102)	6.0	13.4	36	14

Table 11.9-5 (Metric And English Units).GENERAL CHARACTERISTICS OF SURFACE COAL MINES
REFERRED TO IN TABLE 11.9-4ª

^a Reference 4.

			Mine				
Parameter	Required Information	Units	I	Ш	ш	IV	v
Production rate	Coal mined	10 ⁶ ton/yr	1.13	5.0	9.5	3.8	12.0 ^b
Coal transport	Avg. unit train frequency	per day	NA	NA	2	NA	2
Stratigraphic data	Overburden thickness	ft	21	80	90	65	35
	Overburden density	lb/yd ³	4060	3705	3000		_
	Coal seam thicknesses	ft	9,35	15,9	27	2,4,8	70
	Parting thicknesses	ft	50	15	NA	32,16	NA
	Spoils bulking factor	%	22	24	25	20	
	Active pit depth	ft	52	100	114	80	105
Coal analysis data	Moisture	%	10	18	24	38	30
	Ash	%, wet	8	1 0	8	7	6
	Sulfur	%, wet	0.46	0.59	0.75	0.65	0.48
	Heat content	Btu/lb	11000	9632	8 628	8500	8020
Surface disposition	Total disturbed land	acre	168	1030	2112	1975	217
	Active pit	acre	34	202	87	_	71
	Spoils	acre	57	326	144	_	100
	Reclaimed	acre	100	221	950	_	100
	Barren land	acre	-	30	455	_	_
	Associated disturbances	acre	12	186	476	_	46
Storage	Capacity	ton	NA	NA	-	NA	48000
Blasting	Frequency, total	per week	4	4	3	7	7 ^b
	Frequency, overburden	per week	3	0.5	3	NA	7 ^b
	Area blasted, coal	ft ²	16000	40000		30000	_
	Area blasted, overburden	ft ²	20000	_	-	NA	_

Table 11.9-6 (English Units). OPERATING CHARACTERISTICS OF THE COAL MINES REFERRED TO IN TABLE 11.9-4^a

^a Reference 4. NA = not applicable. Dash = no data. ^b Estimate.

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11.10 Coal Cleaning

11.10.1 Process Description^{1-2,9}

Coal cleaning is a process by which impurities such as sulfur, ash, and rock are removed from coal to upgrade its value. Coal cleaning processes are categorized as either physical cleaning or chemical cleaning. Physical coal cleaning processes, the mechanical separation of coal from its contaminants using differences in density, are by far the major processes in use today. Chemical coal cleaning processes are currently being developed, but their performance and cost are undetermined at this time. Therefore, chemical processes are not included in this discussion.

The scheme used in physical coal cleaning processes varies among coal cleaning plants but can generally be divided into four basic phases: initial preparation, fine coal processing, coarse coal processing, and final preparation. A process flow diagram for a typical coal cleaning plant is presented in Figure 11.10-1.

In the initial preparation phase of coal cleaning, the raw coal is unloaded, stored, conveyed, crushed, and classified by screening into coarse and fine coal fractions. The size fractions are then conveyed to their respective cleaning processes.

Fine coal processing and coarse coal processing use similar operations and equipment to separate the contaminants. The primary difference is the severity of operating parameters. The majority of coal cleaning processes use upward currents or pulses of a fluid such as water to fluidize a bed of crushed coal and impurities. The lighter coal particles rise and are removed from the top of the bed. The heavier impurities are removed from the bottom. Coal cleaned in the wet processes then must be dried in the final preparation processes.

Final preparation processes are used to remove moisture from coal, thereby reducing freezing problems and weight and raising the heating value. The first processing step is dewatering, in which a major portion of the water is removed by the use of screens, thickeners, and cyclones. The second step is normally thermal drying, achieved by any one of three dryer types: fluidized bed, flash, and multilouvered. In the fluidized bed dryer, the coal is suspended and dried above a perforated plate by rising hot gases. In the flash dryer, coal is fed into a stream of hot gases for instantaneous drying. The dried coal and wet gases are both drawn up a drying column and into a cyclone for separation. In the multilouvered dryer, hot gases are passed through a falling curtain of coal, which is then raised by flights of a specially designed conveyor.

11.10.2 Emissions And Controls^{1-2,9-10}

Emissions from the initial coal preparation phase of either wet or dry processes consist primarily of fugitive particulate matter (PM) as coal dust from roadways, stock piles, refuse areas, loaded railroad cars, conveyor belt pouroffs, crushers, and classifiers. The major control technique used to reduce these emissions is water wetting. Another technique that applies to unloading, conveying, crushing, and screening operations involves enclosing the process area and circulating air from the area through fabric filters. Uncontrolled emission factors for various types of fugitive sources in coal cleaning facilities can be developed from the equations found in Section 13.2, "Fugitive Dust Sources".



Figure 11.10-1. Typical coal cleaning plant process flow diagram. (Source Classification Codes in parenthesis.)

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The major emission source in the fine or coarse coal processing phases is the air exhaust from the air separation processes (air tables). For the dry cleaning process, these emissions are generated when the coal is stratified by pulses of air. Particulate matter emissions from this source are normally controlled with cyclones followed by fabric filters. Potential emissions from wet cleaning processes are very low.

The major source of emissions from the final preparation phase is the thermal dryer exhaust. This emission stream contains coal particles entrained in the drying gases and volatile organic compounds (VOC) released from the coal, in addition to the standard products of coal combustion resulting from burning coal to generate the hot gases (including carbon monoxide [CO], carbon dioxide [CO₂], VOC, sulfur dioxide [SO₂], and nitrogen oxides [NO_x]). Table 11.10-1 shows emission factors for PM. Emission factors for SO₂, NO_x, VOC, and CO₂ are presented in Table 11.10-2. The most common technology used to control dryer emissions is venturi scrubbers and mist eliminators downstream from the product recovery cyclones. The control efficiency of these techniques for filterable PM ranges from 98 to 99.9 percent. Scrubbers also may achieve between 0 and 95 percent control of SO₂ removal efficiency of the scrubber.

A number of inorganic hazardous air pollutants are found in trace quantities in coal. These include arsenic, beryllium, cadmium, chromium, copper, mercury, manganese, nickel, lead, thorium, and uranium. It is likely that many of these are emitted in trace amounts from crushing, grinding, and drying operations.

The new source performance standards (NSPS) for coal preparation plants were promulgated in January 1976 (40 CFR Subpart Y). These standards specify emission limits for PM from coal cleaning thermal dryers and pneumatic cleaning equipment sources, and opacity limits for fugitive emissions from coal processing and conveying equipment, coal storage systems, and coal transfer and loading systems.

Table 11.10-1. PM EMISSION FACTORS FOR COAL CLEANING^a

	Filterable PM ^b			Condensible PM ^c	
Process	PM	PM-2.5	PM-1.0	Inorganic	Organic
Multilouvered dryer ^d (SCC 3-05-010-03)	3.7	ND	ND	0.057	0.018
Fluidized bed dryer ^e (SCC 3-05-010-01)	26 ^f	3.8 ^g	1.1 ^g	0.034 ^h	0.0075 ^h
Fluidized bed dryer with venturi scrubber ^j (SCC 3-05-010-01)	0.17	ND	ND	0.043	0.0048
Fluidized bed dryer with venturi scrubber and tray scrubber ^k (SCC 3-05-010-01)	0.025	ND	ND	ND	ND
Air tables with fabric filter ^m (SCC 3-05-010-13)	0.032 ⁿ	ND	ND	0.033 ^p	0. 002 69

EMISSION FACTOR RATING: D (except as noted)

^a Emission factor units are lb/ton of coal feed, unless noted. 1 lb/ton = 2 kg/Mg. SCC = Source Classification Code. ND = no data.

- ^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.
- ^c Condensible PM is that PM collected in the impinger portion of a PM sampling train.
- ^d Reference 11. Alternate SCC is 3-05-310-03, which corresponds to units of lb/thousand tons of coal feed. To determine the emission factor for this alternate SCC, multiply the factor in this table by 1,000.
- ^e Alternate SCC is 3-05-310-01, which corresponds to units of lb/thousand tons of coal feed. To determine the emission factor for this alternate SCC, multiply the factor in this table by 1,000.
- f References 12,15.
- ^g References 12,15. EMISSION FACTOR RATING: E. Particle size data from Reference 15 used in conjunction with filterable PM data from References 12 and 15. Actual cut size of PM-2.5 data was 2.7 microns.
- ^h Reference 12.
- ^j References 12-13,15-16,20. See footnote "e" above for alternate SCC.
- ^k Reference 21. Tray scrubber using NaOH as the scrubbing liquid. See footnote "e" above for alternate SCC.
- ^m Alternate SCC is 3-05-310-13, which corresponds to units of lb/thousand tons of coal feed. To determine the emission factor for this alternate SCC, multiply the factor in this table by 1,000.
- ⁿ References 18-19.
- ^p Reference 19.
- ^q Reference 18.

Table 11.10-2. GASEOUS POLLUTANT EMISSION FACTORS FOR COAL CLEANING^a

Process	VOC ^b	SO ₂	NO _x	CO ₂
Multilouvered dryer ^c (SCC 3-05-010-03)	ND	ND	ND	160
Fluidized bed dryer ^d (SCC 3-05-010-01)	ND	1.4 ^e	0.16 ^f	30 ^g
Fluidized bed dryer with venturi scrubber ^h (SCC 3-05-010-01)	0.098 ^j	k	0.16 ^f	30 ^g
Fluidized bed dryer with venturi scrubber and tray scrubber ^m (SCC 3-05-010-01)	ND	0.072 ⁿ	0.16 ^f	30 ^g

EMISSION FACTOR RATING: D (except as noted)

^a Emission factor units are lb/ton of coal feed, unless noted. 1 lb/ton = 2 kg/Mg.
 SCC = Source Classification Code. ND = no data.

- ^b VOC as methane, measured with an EPA Method 25A sampling train. Measurement may include compounds designated as nonreactive.
- ^c Reference 11. EMISSION FACTOR RATING: E. Alternate SCC is 3-05-310-03, which corresponds to units of lb/thousand tons of coal feed. To determine the emission factor for this alternate SCC, multiply the factor in this table by 1,000.
- ^d Alternate SCC is 3-05-310-01, which corresponds to units of lb/thousand tons of coal feed. To determine the emission factor for this alternate, SCC, multiply the factor in this table by 1,000.
- ^e References 12, 14, 17. EMISSION FACTOR RATING: E.
- ^f References 12,14,21. Includes NO_x measurements before and after control devices that are not expected to provide control of NO_x emissions.
- ^g References 12-16,20. Includes CO₂ measurements before and after control devices that are not expected to provide control of CO₂ emissions.
- ^h See footnote "d" above for alternate SCC.
- ^j References 13-14.
- ^k Venturi scrubbers may achieve between 0 and 95% control of SO₂ emissions. The use of a neutralizing agent in the scrubber water increases the SO₂ control efficiency.
- ^m Venturi scrubber followed by tray scrubber using a NaOH solution as the scrubbing liquid. See footnote "d" above for alternate SCC.
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11.11 Coal Conversion

In addition to its direct use for combustion, coal can be converted to organic gases and liquids, thus allowing the continued use of conventional oil- and gas-fired processes when oil and gas supplies are not available. Currently, there is little commercial coal conversion in the United States. Consequently, it is very difficult to determine which of the many conversion processes will be commercialized in the future. The following sections provide general process descriptions and general emission discussions for high-, medium- and low-Btu gasification (gasifaction) processes and for catalytic and solvent extraction liquefaction processes.

11.11.1 Process Description¹⁻²

11.11.1.1 Gasification -

One means of converting coal to an alternate form of energy is gasification. In this process, coal is combined with oxygen and steam to produce a combustible gas, waste gases, char, and ash. The more than 70 coal gasification systems available or being developed in 1979 can be classified by the heating value of the gas produced and by the type of gasification reactor used. High-Btu gasification systems produce a gas with a heating value greater than 900 Btu/scf (33,000 J/m³). Medium-Btu gasifiers produce a gas having a heating value between 250 - 500 Btu/scf (9,000 - 19,000 J/m³). Low-Btu gasifiers produce a gas having a heating value of less than 250 Btu/scf (9,000 J/m³).

The majority of the gasification systems consist of 4 operations: coal pretreatment, coal gasification, raw gas cleaning, and gas beneficiation. Each of these operations consists of several steps. Figure 11.11-1 is a flow diagram for an example coal gasification facility.

Generally, any coal can be gasified if properly pretreated. High-moisture coals may require drying. Some caking coals may require partial oxidation to simplify gasifier operation. Other pretreatment operations include crushing, sizing, and briqueting of fines for feed to fixed bed gasifiers. The coal feed is pulverized for fluid or entrained bed gasifiers.

After pretreatment, the coal enters the gasification reactor where it reacts with oxygen and steam to produce a combustible gas. Air is used as the oxygen source for making low-Btu gas, and pure oxygen is used for making medium- and high-Btu gas (inert nitrogen in the air dilutes the heating value of the product). Gasification reactors are classified by type of reaction bed (fixed, entrained, or fluidized), the operating pressure (pressurized or atmospheric), the method of ash removal (as molten slag or dry ash), and the number of stages in the gasifier (1 or 2). Within each class, gasifiers have similar emissions.

The raw gas from the gasifier contains varying concentrations of carbon monoxide (CO), carbon dioxide (CO₂), hydrogen, methane, other organics, hydrogen sulfide (H₂S), miscellaneous acid gases, nitrogen (if air was used as the oxygen source), particulates, and water. Four gas purification processes may be required to prepare the gas for combustion or further beneficiation: particulate removal, tar and oil removal, gas quenching and cooling, and acid gas removal. The primary function of the particulate removal process is the removal of coal dust, ash, and tar aerosols in the raw product gas. During tar and oil removal and gas quenching and cooling, tars and oils are condensed, and other impurities such as ammonia are scrubbed from raw product gas using either aqueous or organic scrubbing liquors. Acid gases such as H_2S , COS, CS₂, mercaptans, and CO₂ can



Figure 11.11-1. Flow diagram of typical coal gasification plant.

11.11-2

be removed from gas by an acid gas removal process. Acid gas removal processes generally absorb the acid gases in a solvent, from which they are subsequently stripped, forming a nearly pure acid gas waste stream with some hydrocarbon carryover. At this point, the raw gas is classified as either a low-Btu or medium-Btu gas.

To produce high-Btu gas, the heating value of the medium-Btu gas is raised by shift conversion and methanation. In the shift conversion process, H_2O and a portion of the CO are catalytically reacted to form CO_2 and H_2 . After passing through an absorber for CO_2 removal, the remaining CO and H_2 in the product gas are reacted in a methanation reactor to yield CH_4 and H_2O .

There are also many auxiliary processes accompanying a coal gasification facility, which provide various support functions. Among the typical auxiliary processes are oxygen plant, power and steam plant, sulfur recovery unit, water treatment plant, and cooling towers.

11.11.1.2 Liquefaction -

Liquefaction is a conversion process designed to produce synthetic organic liquids from coal. This conversion is achieved by reducing the level of impurities and increasing the hydrogen-to-carbon ratio of coal to the point that it becomes fluid. There were over 20 coal liquefaction processes in various stages of development by both industry and Federal agencies in 1979. These processes can be grouped into 4 basic liquefaction techniques:

- Indirect liquefaction
- Pyrolysis
- Solvent extraction
- Catalytic liquefaction

Indirect liquefaction involves the gasification of coal followed by the catalytic conversion of the product gas to a liquid. Pyrolysis liquefaction involves heating coal to very high temperatures, thereby cracking the coal into liquid and gaseous products. Solvent extraction uses a solvent generated within the process to dissolve the coal and to transfer externally produced hydrogen to the coal molecules. Catalytic liquefaction resembles solvent extraction, except that hydrogen is added to the coal with the aid of a catalyst.

Figure 11.11-2 presents the flow diagram of a typical solvent extraction or catalytic liquefaction plant. These coal liquefaction processes consist of 4 basic operations: coal pretreatment, dissolution and liquefaction, product separation and purification, and residue gasification.

Coal pretreatment generally consists of coal pulverizing and drying. The dissolution of coal is best effected if the coal is dry and finely ground. The heater used to dry coal is typically coal fired, but it may also combust low-BTU-value product streams or may use waste heat from other sources.

The dissolution and liquefaction operations are conducted in a series of pressure vessels. In these processes, the coal is mixed with hydrogen and recycled solvent, heated to high temperatures, dissolved, and hydrogenated. The order in which these operations occur varies among the liquefaction processes and, in the case of catalytic liquefaction, involves contact with a catalyst. Pressures in these processes range up to 2000 psig (14,000 Pa), and temperatures range up to 900°F (480°C). During the dissolution and liquefaction process, the coal is hydrogenated to liquids and some gases, and the oxygen and sulfur in the coal are hydrogenated to H_2O and H_2S .



Figure 11.11-2. Flow diagram for an example coal liquefaction facility.

After hydrogenation, the liquefaction products are separated through a series of flash separators, condensers, and distillation units into a gaseous stream, various product liquids, recycle solvent, and mineral residue. The gases from the separation process are separated further by absorption into a product gas stream and a waste acid gas stream. The recycle solvent is returned to the dissolution/liquefaction process, and the mineral residue of char, undissolved coal, and ash is used in a conventional gasification plant to produce hydrogen.

The residue gasification plant closely resembles a conventional high-Btu coal gasifaction plant. The residue is gasified in the presence of oxygen and steam to produce CO, H_2 , H_2O , other waste gases, and particulates. After treatment for removal of the waste gases and particulates, the CO and H_2O go into a shift reactor to produce CO_2 and additional H_2 . The H_2 -enriched product gas from the residue gasifier is used subsequently in the hydrogenation of the coal.

There are also many auxiliary processes accompanying a coal liquefaction facility that provide various support functions. Among the typical auxiliary processes are oxygen plant, power and steam plant, sulfur recovery unit, water treatment plant, cooling towers, and sour water strippers.

11.11.2 Emissions And Controls¹⁻³

Although characterization data are available for some of the many developing coal conversion processes, describing these data in detail would require a more extensive discussion than possible here. So, this section will cover emissions and controls for coal conversion processes on a qualitative level only.

11.11.2.1 Gasification -

All of the major operations associated with low-, medium- and high-Btu gasification technology (coal pretreatment, gasification, raw gas cleaning, and gas beneficiation) can produce potentially hazardous air emissions. Auxiliary operations, such as sulfur recovery and combustion of fuel for electricity and steam generation, could account for a major portion of the emissions from a gasification plant. Discharges to the air from both major and auxiliary operations are summarized and discussed in Table 11.11-1.

Dust emissions from coal storage, handling, and crushing/sizing can be controlled with available techniques. Controlling air emissions from coal drying, briqueting, and partial oxidation processes is more difficult because of the volatile organics and possible trace metals liberated as the coal is heated.

The coal gasification process itself appears to be the most serious potential source of air emissions. The feeding of coal and the withdrawal of ash release emissions of coal or ash dust and organic and inorganic gases that are potentially toxic and carcinogenic. Because of their reduced production of tars and condensable organics, slagging gasifiers pose less severe emission problems at the coal inlet and ash outlet.

Gasifiers and associated equipment also will be sources of potentially hazardous fugitive leaks. These leaks may be more severe from pressurized gasifiers and/or gasifiers operating at high temperatures.

Raw gas cleaning and gas beneficiation operations appear to be smaller sources of potential air emissions. Fugitive emissions have not been characterized but are potentially large. Emissions from the acid gas removal process depend on the kind of removal process employed at a plant. Processes used for acid gas removal may remove both sulfur compounds and CO_2 or may be operated

Table 11.11-1. SUMMARY OF EMISSIONS FROM COAL GASIFICATION PLANTS¹⁻³

Operation/Emission Source/Stream	Characterization Of Emission	Summary Of Emission Control Choices
Coal Pretreatment		
Storage, handling, and crushing/sizing - Dust emissions	Emissions from coal storage, handling, and crushing/sizing mainly consist of coal dust. These emissions vary from site to site depending on wind velocities, coal and pile size, and water content.	Water sprays and polymer coatings are used to control dust emissions from coal storage piles. Water sprays and enclosed equipment are vented to a baghouse to reduce or capture particulates from coal handling. Emissions from crushing/sizing are also usually vented to a baghouse or other particulate control device.
Drying, partial oxidation, and briquetting - Vent gases	These emissions comprise coal dust and combustion gases along with a variety of organic compounds devolatilized from the coal. Organic species have not been determined.	In addition to particulate control devices, afterburners may be needed to destroy organic species.
Coal gasification		
Feeding - Vent gases	These gases contain all the hazardous species found in the raw product gas exiting the gasifier including H_2S , COS, CS ₂ , SO ₂ , CO, NH ₃ , CH ₄ , HCN, tars and oils, particulates, and trace organics and inorganics. The size and composition of this stream depend on the type of gasifier, e. g., fluidized bed gasifiers emit substantially fewer tars and oils than fixed bed gasifiers.	This stream could represent a significant environmental problem. Control could include scrubbing or incineration (to capture or destroy the most hazardous species), or venting to the raw product gas or gasifier inlet air. The desired control depends on the type and size of gasification facility. Screw fed conveyors can be used instead of lock hoppers.
Ash removal - Vent gases	Emissions from ash removal and disposal depend on the type of gasifier. Ash dust will be released from all gasifiers that are not slagging or agglomerating ash units. If contaminated water is used for ash quenching, volatile organic and inorganic species may be released from the quench liquor.	These emissions have not been sufficiently characterized to recommend necessary controls. Particluate or organic emission controls could be needed. Clean water may be used for quenching to avoid the potential emission of hazardous volatile organic and inorganic species.
Startup - Vent gases	This vent gas initially resembles a coal combustion gas in composition. As the operating temperature of the gas increases, the startup gas begins to resemble the raw product gas.	A flare can incinerate the combustible constitutents in the startup gas, but heavy tars and coal particulates will affect the performance of the flare. Potential problems with tars and particulates can be avoided by using charcoal or coke as the startup fuel.

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Table 11.11-1 (cont.).

Operation/Emission Source/Stream	Characterization Of Emission	Summary Of Emission Control Choices
Fugitives	These emissions have not been characterized, but they comprise hazardous species found in the raw product gas such as H_2S , COS, CS ₂ , CO, HCN, CH ₄ , and others.	Control methods mainly involve good maintenance and operating practices.
Raw Gas Cleaning/Benefication		
Fugitives	These emissions have not been characterized, but they comprise hazardous species found in the various gas streams. Other emissions result from leaks from pump seals, valves, flanges, and byproduct storage tanks.	Control methods mainly involve good maintenance and operating practices.
Acid Gas Removal - Tail gases	The composition of this stream highly depends on the kind of acid gas removal employed Processes featuring the direct removal and conversion of sulfur species in a single step (e. g., the Stretford process) produce tail gases containing small amounts of HN_3 and other species. Processes absorbing and consequently desorbing a concentrated acid gas stream require a sulfur recovery process to avoid the emission of highly toxic gases having quantities of H_2S .	Some tail gas streams (from the Stretford process, for example) are probably not very hazardous. These streams have not been characterized, nor have control technology needs been demonstrated. Tail gases from other processes always require the removal of sulfur species. Trace constituents such as organics, trace elements and cyanides affect the performance of the auxiliary sulfur removal processes.
Auxiliary Operations		
Sulfur recovery	See Section 8.13	
Power and steam generation	See Section 1.1	
Waste Water Treatment - Expansion gases	These streams comprise volatile organic and inorganic species that desorb from quenching/cooling liquor. The streams potentially include all the hazardous species found in the product gas.	Three streams could pose significant environmental problems. Potential controls are generally similar to those needed to treat coal feeding vent gases.
Cooling Towers - Exhaust gas	Emissions from cooling towers are usually minor. However, if contaminated water is used as cooling water makeup, volatile organic and inorganic species from the contaminated water could be released.	The potential emission of hazardous volatile organic and inorganic species may be avoided by using clean water for cooling.

selectively to remove only the sulfur compounds. Typically, the acid gases are stripped from the solvent and processed in a sulfur plant. Some processes, however, directly convert the absorbed hydrogen sulfide to elemental sulfur. Emissions from these direct conversion processes (e. g., the Stretford process) have not been characterized but are probably minor, consisting of CO_2 , air, moisture, and small amounts of NH_3 .

Emission controls for 2 auxiliary processes (power and steam generation and sulfur recovery) are discussed elsewhere in this document (Sections 1.1 and 8.13, respectively). Gases stripped or desorbed from process waste waters are potentially hazardous, since they contain many of the components found in the product gas. These include sulfur and nitrogen species, organics, and other species that are toxic and potentially carcinogenic. Possible controls for these gases include incineration, byproduct recovery, or venting to the raw product gas or inlet air. Cooling towers are usually minor emission sources, unless the cooling water is contaminated.

11.11.2.2 Liquefaction -

The potential exists for generation of significant levels of atmospheric pollutants from every major operation in a coal liquefaction facility. These pollutants include coal dust, combustion products, fugitive organics, and fugitive gases. The fugitive organics and gases could include carcinogenic polynuclear organics, and toxic gases such as metal carbonyls, hydrogen sulfides, ammonia, sulfurous gases, and cyanides. Many studies are currently underway to characterize these emissions and to establish effective control methods. Table 11.11-2 presents information now available on liquefaction emissions.

Emissions from coal preparation include coal dust from the many handling operations and combustion products from the drying operation. The most significant pollutant from these operations is the coal dust from crushing, screening, and drying activities. Wetting down the surface of the coal, enclosing the operations, and venting effluents to a scrubber or fabric filter are effective means of particulate control.

A major source of emissions from the coal dissolution and liquefaction operation is the atmospheric vent on the slurry mix tank. The slurry mix tank is used for mixing feed coal and recycle solvent. Gases dissolved in the recycle solvent stream under pressure will flash from the solvent as it enters the unpressurized slurry mix tank. These gases can contain hazardous volatile organics and acid gases. Control techniques proposed for this source include scrubbing, incineration, or venting to the combustion air supply for either a power plant or a process heater.

Emissions from process heaters fired with waste process gas or waste liquids will consist of standard combustion products. Industrial combustion emission sources and available controls are discussed in Section 1.1.

The major emission source in the product separation and purification operations is the sulfur recovery plant tail gas. This can contain significant levels of acid or sulfurous gases. Emission factors and control techniques for sulfur recovery tail gases are discussed in Section 8.13.

Emissions from the residue gasifier used to supply hydrogen to the system are very similar to those for coal gasifiers previously discussed in this section.

Emissions from auxiliary processes include combustion products from onsite steam/electric power plant and volatile emissions from the waste water system, cooling towers, and fugitive emission sources. Volatile emissions from cooling towers, waste water systems, and fugitive

Operation/Emission Source/Stream	Characterization Of Emission	Summary Of Emission Control Choices
Coal Preparation		
Storage, handling and crushing/sizing	Emissions primarily consist of fugitive coal dust generated at transfer points and points exposed to wind erosion. A potentially significant source.	Water sprays and polymer coatings are used to control dust from storage sites. Water sprays and enclosures vented to baghouses are effective on crushing and sizing operations.
Drying	Emissions include coal dust, combustion products from heater, and organics volatilized from the coal. A potentially significant particulate source.	Scrubbers, electrostatic precipitators, and baghouses are effective coal dust controls. Low drying temperatures reduce organics formation.
Coal Dissolution and Liquefaction		
Process heater (fired with low-grade fuel gas)	Emissions consist of combustion products (particulates, CO, SO ₂ , NO _x , and HC).	Fuel desulfurization for SO_2 control and combustion modifications for reduced CO, HC, and NO_x
Slurry mix tank	Evolution of dissolved gases from recycle solvent (HC, acid gases, organics) due to low pressure (atmospheric) of tank. Some pollutants are toxic even in small quantities.	Controls might include scrubbing, incineration, or venting to heater combustion air supply.
Product Separation and Liquefaction - Sulfur recovery plant	Tail gases containing acids (H_2S , SO_2 , COS , CS_2 , NH_3 , and particulate sulfur).	Venting to tail gas treatment plant, or operating sulfur recovery plant at higher efficiency.
Residue Gasification	See 11.11.2.1 in text	
Auxiliary Processes		
Power and steam generation	See Section 1.1	
Waste water system	Volatile organics, acid gases, ammonia, and cyanides, that evolve from various waste water collection and treating systems.	Enclosure of the waste water system and venting gases from system to scrubbers or incinerators.
Cooling towers	Any chemical in the facility can leak to cooling water systems from leaking heat exchangers and can be stripped to the atmosphere in the cooling tower.	Good heat exchanger maintenance and surveillance of cooling water quality.
Fugitives	All organic and gaseous compounds in plant can leak from valves, flanges, seals, and sample ports. This may be the largest source of hazardous organics.	Good housekeeping, frequent maintenance, and selection of durable components are major control techniques.

Table 11.11-2. SUMMARY OF EMISSIONS FROM A COAL GASIFICATION PLANTS¹

emission sources possibly can include every chemical compound present in the plant. These sources will be the most significant and most difficult to control in a coal liquefaction facility. Compounds that can be present include hazardous organics, metal carbonyls, trace elements such as mercury, and toxic gases such as CO_2 , H_2S , HCN, NH_3 , COS, and CS_2 .

Emission controls for waste water systems involve minimizing the contamination of water with hazardous compounds, enclosing the waste water systems, and venting the waste water systems to a scrubbing or incinerating system. Cooling tower controls focus on good heat exchanger maintenance, to prevent chemical leaks into the system, and on surveillance of cooling water quality. Fugitive emissions from various valves, seals, flanges, and sampling ports are individually small but collectively very significant. Diligent housekeeping and frequent maintenance, combined with a monitoring program, are the best controls for fugitive sources. The selection of durable low leakage components, such as double mechanical seals, is also effective.

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11.12 Concrete Batching

11.12 Process Description¹⁻⁴

Concrete is composed essentially of water, cement, sand (fine aggregate), and coarse aggregate. Coarse aggregate may consist of gravel, crushed stone, or iron blast furnace slag. Some specialty aggregate products could be either heavyweight aggregate (of barite, magnetite, limonite, ilmenite, iron, or steel) or lightweight aggregate (with sintered clay, shale, slate, diatomaceous shale, perlite, vermiculite, slag, pumice, cinders, or sintered fly ash). Concrete batching plants store, convey, measure, and discharge these constituents into trucks for transport to a job site. In some cases, concrete is prepared at a building construction site or for the manufacture of concrete products such as pipes and prefabricated construction parts. Figure 11.12-1 is a generalized process diagram for concrete batching.

The raw materials can be delivered to a plant by rail, truck, or barge. The cement is transferred to elevated storage silos pneumatically or by bucket elevator. The sand and coarse aggregate are transferred to elevated bins by front end loader, clam shell crane, belt conveyor, or bucket elevator. From these elevated bins, the constituents are fed by gravity or screw conveyor to weigh hoppers, which combine the proper amounts of each material.

Truck mixed (transit mixed) concrete involves approximately 75 percent of U. S. concrete batching plants. At these plants, sand, aggregate, cement, and water are all gravity fed from the weigh hopper into the mixer trucks. The concrete is mixed on the way to the site where the concrete is to be poured. Central mix facilities (including shrink mixed) constitute the other one-fourth of the industry. With these, concrete is mixed and then transferred to either an open bed dump truck or an agitator truck for transport to the job site. Shrink mixed concrete is concrete that is partially mixed at the central mix plant and then completely mixed in a truck mixer on the way to the job site. Dry batching, with concrete mixed and hauled to the construction site in dry form, is seldom, if ever, used.

11.12-2 Emissions And Controls⁵⁻⁷

Emission factors for concrete batching are given in Tables 11.12-1 and 11.12-2, with potential air pollutant emission points shown. Particulate matter, consisting primarily of cement dust but including some aggregate and sand dust emissions, is the only pollutant of concern. All but one of the emission points are fugitive in nature. The only point source is the transfer of cement to the silo, and this is usually vented to a fabric filter or "sock". Fugitive sources include the transfer of sand and aggregate storage piles. The amount of fugitive emissions generated during the transfer of sand and aggregate depends primarily on the surface moisture content of these materials. The extent of fugitive emission control varies widely from plant to plant.

Types of controls used may include water sprays, enclosures, hoods, curtains, shrouds, movable and telescoping chutes, and the like. A major source of potential emissions, the movement of heavy trucks over unpaved or dusty surfaces in and around the plant, can be controlled by good maintenance and wetting of the road surface.

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Figure 11.12-1. Typical concrete batching process.

	Filterable ^b			Condensable PM ^c	
Source (SCC)	PM	RATING	PM-10	Inorganic	Organic
Sand and aggregate transfer to elevated bin (3-05-011-06) ^d	0.014	E	ND	ND	ND
Cement unloading to elevated storage silo					
Pneumatic ^e	0.13	D	ND	ND	ND
Bucket elevator (3-05-011-07) ^f	0.12	Е	ND	ND	ND
Weigh hopper loading (3-05-011-8) ^g	0.01	Е	ND	ND	ND
Mixer loading (central mix) (3-05-011-09) ^g	0.02	Ē	ND	ND	ND
Truck loading (truck mix) (3-05-011-10) ^g	0.01	E	ND	ND	ND
Vehicle traffic (unpaved roads) (3-05-011) ^h	4.5	С	ND	ND	ND
Wind erosion from sand and aggregate storage piles (3-05-011) ⁱ	3.9	D	ND	ND	ND
Total process emissions (truck mix)(3-05-011) ^j	0.05	E	ND	ND	ND

Table 11.12-1 (Metric Units). EMISSION FACTORS FOR CONCRETE BATCHING^a

^a Factors represent uncontrolled emissions unless otherwise noted. All emission factors are in kg/Mg of material mixed unless noted. Based on a typical yd³ weighing 1.818 kg (4,000 lb) and containing 227 kg (500 lb) cement, 564 kg (1,240 lb) sand, 864 kg (1,900 lb) coarse aggregate, and 164 kg (360 lb) water. SCC = Source Classification Code. ND = no data.

- ^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.
- ^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.
- ^d Reference 6.
- ^e For uncontrolled emissions measured before filter. Based on 2 tests on pneumatic conveying controlled by a fabric filter.
- ^f Reference 7. From test of mechanical unloading to hopper and subsequent transport of cement by enclosed bucket elevator to elevated bins with fabric socks over bin vent.
- ^g Reference 5. Engineering judgment, based on observations and emissions tests of similar controlled sources.
- ^h From Section 13.2-1, with k = 0.8, s = 12, S = 20, W = 20, w = 14, and p = 100; units of kg/vehicle kilometers traveled; based on facility producing 23,100 m³/yr (30,000 yd³/yr) of concrete, with average truck load of 6.2 m³ (8 yd³) and plant road length of 161 meters (0.1 mile).
- ⁱ From Section 11.19-1, for emissions < 30 micrometers from inactive storage piles; units of kg/hectare/day.
- ^j Based on pneumatic conveying of cement at a truck mix facility. Does not include vehicle traffic or wind erosion from storage piles.

	Filterable ^c			Condensable PM ^d	
Source (SCC)	PM	RATING	PM-10	Inorganic	Organic
Sand and aggregate transfer to elevated bin (3-05-011-06) ^e	0.029 (0.05)	E	ND	ND	ND
Cement unloading to elevated storage silo					
Pneumatic ^f	0.27 (0.07)	D	ND	ND	ND
Bucket elevator (3-05-011-07) ^g	0.24 (0.06)	Ε	ND	ND	ND
Weigh hopper loading (3-05-011-08) ^h	0.02 (0.04)	E	ND	ND	ND
Mixer loading (central mix) (3-05-011-09) ^h	0.04 (0.07)	E	ND	ND	ND
Truck loading (truck mix) (3-05-011-10) ^b	0.02 (0.04)	E	ND	ND	ND
Vehicle traffic (unpaved roads) (3-05-011) ⁱ	16 (0.02)	С	ND	ND	ND
Wind erosion from sand and aggregate storage piles (3-05-011) ^j	3.5 ^k (0.1) ⁱ	D	ND	ND	ND
Total process emissions (truck mix) (3-05-011) ^m	0.1 (0.2)	E	ND	ND	ND

Table 11.12-2 (English Units). EMISSION FACTORS FOR CONCRETE BATCHING^{a,b}

^a Factors represent uncontrolled emissions unless otherwise noted. All emission factors are in lb/ton (lb/yd^3) of material mixed unless noted. SCC = Source Classification Code. ND = no data.

^b Based on a typical yd³ weighing 1.818 kg (4,000 lb) and containing 227 kg (500 lb) cement, 564 kg (1.240 lb) sand, 864 kg (1.900 lb) coarse aggregate, and 164 kg (360 lb) water.

- ^c Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.
- ^d Condensable PM is that PM collected in the impinger portion of a PM sampling train.
- ^e Reference 6.
- ^f For uncontrolled emissions measured before filter. Based on 2 tests on pneumatic conveying controlled by a fabric filter.
- ^g Reference 7. From test of mechanical unloading to hopper and subsequent transport of cement by enclosed bucket elevator to elevated bins with fabric socks over bin vent.

^h Reference 5. Engineering judgment, based on observations and emission tests of similar controlled sources.

ⁱ From Section 13.2.1, with k = 0.8, s = 12, S = 20, W = 20, w = 14, and p = 100; units of lb/vehicle miles traveled; based on facility producing 23,100 m³/yr (30,000 yd³/yr) of concrete, with average truck load of 6.2 m³ (8 yd³) and plant road length of 161 meters (0.1 mile).

^j From Section 11.19.1, for emissions < 30 micrometers from inactive storage piles.

- ¹ Assumes 1,011 m² (1/4 acre) of sand and aggregate storage at plant with production of 23,000 m³/yr (30,000 yd³/yr).
- ^m Based on pneumatic conveying of cement at a truck mix facility; does not include vehicle traffic or wind erosion from storage piles.

Predictive equations that allow for emission factor adjustment based on plant-specific conditions are given in Chapter 13. Whenever plant specific data are available, they should be used in lieu of the fugitive emission factors presented in Table 11.12-1.

^k Units of lb/acre/day.

References For Section 11.12

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- 3. Telephone and written communication between Edwin A. Pfetzing, PEDCo Environmental, Inc., Cincinnati, OH, and Richard Morris and Richard Meininger, National Ready Mix Concrete Association, Silver Spring, MD, May 1984.
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- 5. Technical Guidance For Control Of Industrial Process Fugitive Particulate Emissions, EPA-450/3-77-010, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1977.
- 6. Fugitive Dust Assessment At Rock And Sand Facilities In The South Coast Air Basin, Southern California Rock Products Association and Southern California Ready Mix Concrete Association, Santa Monica, CA, November 1979.
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11.13 Glass Fiber Manufacturing

11.13.1 General¹⁻⁴

Glass fiber manufacturing is the high-temperature conversion of various raw materials (predominantly borosilicates) into a homogeneous melt, followed by the fabrication of this melt into glass fibers. The 2 basic types of glass fiber products, textile and wool, are manufactured by similar processes. A typical diagram of these processes is shown in Figure 11.13-1. Glass fiber production can be segmented into 3 phases: raw materials handling, glass melting and refining, and wool glass fiber forming and finishing, this last phase being slightly different for textile and wool glass fiber production.

Raw Materials Handling -

The primary component of glass fiber is sand, but it also includes varying quantities of feldspar, sodium sulfate, anhydrous borax, boric acid, and many other materials. The bulk supplies are received by rail car and truck, and the lesser-volume supplies are received in drums and packages. These raw materials are unloaded by a variety of methods, including drag shovels, vacuum systems, and vibrator/gravity systems. Conveying to and from storage piles and silos is accomplished by belts, screws, and bucket elevators. From storage, the materials are weighed according to the desired product recipe and then blended well before their introduction into the melting unit. The weighing, mixing, and charging operations may be conducted in either batch or continuous mode.

Glass Melting And Refining -

In the glass melting furnace, the raw materials are heated to temperatures ranging from 1500 to 1700°C (2700 to 3100°F) and are transformed through a sequence of chemical reactions to molten glass. Although there are many furnace designs, furnaces are generally large, shallow, and well-insulated vessels that are heated from above. In operation, raw materials are introduced continuously on top of a bed of molten glass, where they slowly mix and dissolve. Mixing is effected by natural convection, gases rising from chemical reactions, and, in some operations, by air injection into the bottom of the bed.

Glass melting furnaces can be categorized by their fuel source and method of heat application into 4 types: recuperative, regenerative, unit, and electric melter. The recuperative, regenerative, and unit melter furnaces can be fueled by either gas or oil. The current trend is from gas-fired to oilfired. Recuperative furnaces use a steel heat exchanger, recovering heat from the exhaust gases by exchange with the combustion air. Regenerative furnaces use a lattice of brickwork to recover waste heat from exhaust gases. In the initial mode of operation, hot exhaust gases are routed through a chamber containing a brickwork lattice, while combustion air is heated by passage through another corresponding brickwork lattice. About every 20 minutes, the airflow is reversed, so that the combustion air is always being passed through hot brickwork previously heated by exhaust gases. Electric furnaces melt glass by passing an electric current through the melt. Electric furnaces are either hot-top or cold-top. The former use gas for auxiliary heating, and the latter use only the electric current. Electric furnaces are currently used only for wool glass fiber production because of the electrical properties of the glass formulation. Unit melters are used only for the "indirect" marble melting process, getting raw materials from a continuous screw at the back of the furnace adjacent to the exhaust air discharge. There are no provisions for heat recovery with unit melters.



Figure 11.13-1. Typical flow diagram of the glass fiber production process.

In the "indirect" melting process, molten glass passes to a forehearth, where it is drawn off, sheared into globs, and formed into marbles by roll-forming. The marbles are then stress-relieved in annealing ovens, cooled, and conveyed to storage or to other plants for later use. In the "direct" glass fiber process, molten glass passes from the furnace into a refining unit, where bubbles and particles are removed by settling, and the melt is allowed to cool to the proper viscosity for the fiber forming operation.

Wool Glass Fiber Forming And Finishing -

Wool fiberglass is produced for insulation and is formed into mats that are cut into batts. (Loose wool is primarily a waste product formed from mat trimming, although some is a primary product, and is only a small part of the total wool fiberglass produced. No specific emission data for loose wool production are available.) The insulation is used primarily in the construction industry and is produced to comply with ASTM C167-64, the "Standard Test Method for Thickness and Density of Blanket- or Batt-Type Thermal Insulating Material".

Wool fiberglass insulation production lines usually consist of the following processes: (1) preparation of molten glass, (2) formation of fibers into a wool fiberglass mat, (3) curing the binder-coated fiberglass mat, (4) cooling the mat, and (5) backing, cutting, and packaging the insulation. Fiberglass plants contain various sizes, types, and numbers of production lines, although a typical plant has 3 lines. Backing (gluing a flat flexible material, usually paper, to the mat), cutting, and packaging operations are not significant sources of emissions to the atmosphere.

The trimmed edge waste from the mat and the fibrous dust generated during the cutting and packaging operations are collected by a cyclone and either are transported to a hammer mill to be chopped into blown wool (loose insulation) and bulk packaged or are recycled to the forming section and blended with newly formed product.

During the formation of fibers into a wool fiberglass mat (the process known as "forming" in the industry), glass fibers are made from molten glass, and a chemical binder is simultaneously sprayed on the fibers as they are created. The binder is a thermosetting resin that holds the glass fibers together. Although the binder composition varies with product type, typically the binder consists of a solution of phenol-formaldehyde resin, water, urea, lignin, silane, and ammonia. Coloring agents may also be added to the binder. Two methods of creating fibers are used by the industry. In the rotary spin process, depicted in Figure 11.13-2, centrifugal force causes molten glass to flow through small holes in the wall of a rapidly rotating cylinder to create fibers that are broken into pieces by an air stream. This is the newer of the 2 processes and dominates the industry today. In the flame attenuation process, molten glass flows by gravity from a furnace through numerous small orifices to create threads that are then attenuated (stretched to the point of breaking) by high velocity, hot air, and/or a flame. After the glass fibers are created (by either process) and sprayed with the binder solution, they are collected by gravity on a conveyor belt in the form of a mat.

The conveyor carries the newly formed mat through a large oven to cure the thermosetting binder and then through a cooling section where ambient air is drawn down through the mat. Figure 11.13-3 presents a schematic drawing of the curing and cooling sections. The cooled mat remains on the conveyor for trimming of the uneven edges. Then, if product specifications require it, a backing is applied with an adhesive to form a vapor barrier. The mat is then cut into batts of the desired dimensions and packaged.

Textile Glass Fiber Forming And Finishing -

Molten glass from either the direct melting furnace or the indirect marble melting furnace is temperature-regulated to a precise viscosity and delivered to forming stations. At the forming



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Figure 11.13-3. Side view of curing oven (indirect heating) and cooling section.

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stations, the molten glass is forced through heated platinum bushings containing numerous very small openings. The continuous fibers emerging from the openings are drawn over a roller applicator, which applies a coating of a water-soluble sizing and/or coupling agent. The coated fibers are gathered and wound into a spindle. The spindles of glass fibers are next conveyed to a drying oven, where moisture is removed from the sizing and coupling agents. The spindles are then sent to an oven to cure the coatings. The final fabrication includes twisting, chopping, weaving, and packaging the fiber.

11.13.2 Emissions And Controls^{1,3,4}

Emissions and controls for glass fiber manufacturing can be categorized by the 3 production phases with which they are associated. Emission factors for the glass fiber manufacturing industry are given in Tables 11.13-1, 11.13-2, and 11.13-3.

Raw Materials Handling -

The major emissions from the raw materials handling phase are fugitive dust and raw material particles generated at each of the material transfer points. Such a point would be where sand pours from a conveyor belt into a storage silo. The 2 major control techniques are wet or moist handling and fabric filters. When fabric filters are used, the transfer points are enclosed, and air from the transfer area is continuously circulated through the fabric filters.

Glass Melting And Refining -

The emissions from glass melting and refining include volatile organic compounds from the melt, raw material particles entrained in the furnace flue gas, and, if furnaces are heated with fossil fuels, combustion products. The variation in emission rates among furnaces is attributable to varying operating temperatures, raw material compositions, fuels, and flue gas flow rates. Of the various types of furnaces used, electric furnaces generally have the lowest emission rates, because of the lack of combustion products and of the lower temperature of the melt surface caused by bottom heating. Emission control for furnaces is primarily fabric filtration. Fabric filters are effective on particulate matter (PM) and sulfur oxides (SO_x) and, to a lesser extent, on carbon monoxide (CO), nitrogen oxides (NO_x), and fluorides. The efficiency of these compounds is attributable to both condensation on filterable PM and chemical reaction with PM trapped on the filters. Reported fabric filter efficiencies on regenerative and recuperative wool furnaces are for PM, 95+ percent; SO_x, 99+ percent; CO, 30 percent; and fluoride, 91 to 99 percent. Efficiencies on other furnaces are lower because of lower emission loading and pollutant characteristics.

Wool Fiber Forming And Finishing -

Emissions generated during the manufacture of wool fiberglass insulation include solid particles of glass and binder resin, droplets of binder, and components of the binder that have vaporized. Glass particles may be entrained in the exhaust gas stream during forming, curing, or cooling operations. Test data show that approximately 99 percent of the total emissions from the production line are emitted from the forming and curing sections. Even though cooling emissions are negligible at some plants, cooling emissions at others may include fugitives from the curing section. This commingling of emissions occurs because fugitive emissions from the open terminal end of the curing oven may be induced into the cooling exhaust ductwork and be discharged into the atmosphere. Solid particles of resin may be entrained in the gas stream in either the curing or cooling sections. Droplets of organic binder may be entrained in the gas stream is cooled. Some of the liquid binder used in the forming section is vaporized by the elevated temperatures in the forming and curing processes. Much of the vaporized material will condense when the gas stream cools in the ductwork or in the emission control device.

Table 11.13-1 (Metric Units). EMISSION FACTORS FOR GLASS FIBER MANUFACTURING^a

EMISSION FACTOR RATING: B

	Filterable ^b		Condens	able PM ^c
	РМ	PM-10	Inorganic	Organic
Source	kg/Mg Of Material Processed	kg/Mg Of Material Processed	kg/Mg Of Material Processed	kg/Mg of Material Processed
Unloading and conveying (SCC 3-05-012-21) ^d	1.5	ND	ND	ND
Storage bins (SCC 3-05-012-22) ^d	0.1	ND	ND	ND
Mixing and weighing (SCC 3-05-012-23) ^d	0.3	ND	ND	ND
Crushing and batch charging (SCC 3-05-012-24) ^d	Neg	ND	ND	ND
Glass furnace - wool ^e Electric (SCC 3-05-012-03) Gas - regenerative (SCC 3-05-012-02) Gas - recuperative (SCC 3-05-012-01) Gas - unit melter (SCC 3-05-012-07) Glass furnace - textile ^e	0.25 11 13 - 15 4.5	ND ND ND ND	ND ND ND ND	ND ND ND ND
Gas - recuperative (SCC 3-05-012-12) Gas - regenerative (SCC 3-05-012-11) Gas - unit melter (SCC 3-05-012-13)	1 8 3	ND ND ND	ND ND ND	ND ND ND
Forming - wool Flame attenuation (SCC 3-05-012-08) ^e	1	ND	ND	ND
Forming - textile (SCC 3-05-012-14) ^e	0.5	ND	ND	ND
Oven curing - wool Flame attenuation (SCC 3-05-012-09) ^e	3	ND	ND	ND
Oven curing and cooling - textile (SCC 3-05-012-15) ^e	0.6	ND	ND	ND

Table 11.13-1 (cont	t.).
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	Filterable ^b PM PM-10		Condens	able PM ^c
			Inorganic	Organic
Source	kg/Mg Of Material Processed	kg/Mg Of Material Processed	kg/Mg Of Material Processed	kg/Mg Of Material Processed
Rotary spin wool glass manufacturing (3-05-012-04) ^f				
R-19	17.81	ND	ND	4.25
R-11	19.61	ND	ND	3.19
Ductboard	27.72	ND	ND	8.55
Heavy density	4.91	ND	ND	· 1.16

^a Factors are uncontrolled, unless otherwise noted. SCC = Source Classification Code. ND = no data. Neg = negligible.
 ^b Filterable PM is that PM collected on or before to the filter of an EPA Method 5 (or equivalent) sampling train.
 ^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d Reference 1.

^e Reference 5.

^f Reference 4. Units are expressed kg/Mg of finished product.

Table 11.13-2 (English Units). EMISSION FACTORS FOR GLASS FIBER MANUFACTURING^a

EMISSION FACTOR RATING: B

	Filterable ^b		Condensa	able PM ^c
	РМ	PM-10	Inorganic	Organic
Source	lb/ton Of Material Processed	lb/ton Of Material Processed	lb/ton Of Material Processed	lb/ton Of Material Processed
Unloading and conveying (SCC 3-05-012-21) ^d	3.0	ND	ND	ND
Storage bins (SCC 3-05-012-22) ^d	0.2	ND	ND	ND
Mixing and weighing (SCC 3-05-012-23) ^d	0.6	ND	ND	ND
Crushing and batch charging (SCC 3-05-012-24) ^d	Neg	ND	ND	ND
Glass furnace - wool ^e Electric (SCC 3-05-012-03) Gas - recuperative (SCC 3-05-012-02) Gas - regenerative (SCC 3-05-012-01) Gas - unit melter (SCC 3-05-012-07)	0.5 22 25 - 30 9	ND ND ND ND	ND ND ND ND	ND ND ND ND
Glass furnace - textile ^e Gas - recuperative (SCC 3-05-012-12) Gas - regenerative (SCC 3-05-012-11) Gas - unit melter (SCC 3-05-012-13)	2 16 6	ND ND ND	ND ND ND	ND ND ND
Forming - wool Flame attenuation (SCC 3-05-012-08) ^e	2	ND	ND	ND
Forming - textile (SCC 3-05-012-14) ^e	1	ND	ND	ND
Oven curing - wool Flame attenuation (SCC 3-05-012-09) ^e	6	ND	ND	ND
Oven curing and cooling - textile (SCC 3-05-012-15) ^e	1.2	ND	ND	ND

	Filterable ^b		Condensable PM ^c	
	РМ	PM-10	Inorganic	Organic
Source	lb/ton Of Material Processed	lb/ton Of Material Processed	lb/ton Of Material Processed	lb/ton Of Material Processed
Rotary spin wool glass manufacturing (SCC 3-05-012-04) ^f				
R-19	36.21	ND	ND	8.52
R-11	39.21	ND	ND	6.37
Ductboard	55.42	ND	ND	17.08
Heavy density	9.81	ND	ND	2.33

^a Factors are uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data. Neg = negligible.
 ^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d Reference 1.

^e Reference 5.

^f Reference 4. Units are lb/ton of finished product.

Table 11.13-3 (Metric Units). EMISSION FACTORS FOR GLASS FIBER MANUFACTURING^a

EMISSION FACTOR RATING: B

	SO _x	NO _x	СО	
Source	kg/Mg Of Material Processed	kg/Mg Of Material Processed	kg/Mg Of Material Processed	
Glass furnace - wool ^b				
Electric (SCC 3-05-012-03)	0.02	0.14	0.025	
Gas - regenerative (SCC 3-05-012-01)	5	2.5	0.13	
Gas - recuperative (SCC 3-05-012-02)	5	0.85	0.13	
Gas - unit melter (SCC 3-05-012-07)	0.3	0.15	0.13	
Glass furnace - textile ^b				
Gas - recuperative (SCC 3-05-012-12)	1.5	10	0.25	
Gas - regenerative (SCC 3-05-012-11)	15	10	0.5	
Gas - unit melter (SCC 3-05-012-13)	ND	10	0.45	
Forming - wool ^b				
Flame attenuation (SCC 3-05-012-08)	NA	NA	NA	
Forming - textile ^b (SCC 3-05-012-14)	NA	NA	NA	
Oven curing - wool ^b				
Flame attenuation (SCC 3-05-012-09)	ND	1	1.8	
Oven curing and cooling - textile ^b (SCC 3-05-012-15)	NA	1.3	0.75	

^a Factors are uncontrolled unless otherwise noted. SCC = Source Classification Code. ND = no data. NA = not applicable. ^b Reference 5.

Table 11.13-4 (English Units). EMISSION FACTORS FOR GLASS FIBER MANUFACTURING^a

EMISSION FACTOR RATING: B

	SO _x	NO _x	СО	
Source	lb/ton Of Material Processed	lb/ton Of Material Processed	lb/ton Of Material Processed	
Glass furnace - wool				
Electric (SCC 3-05-012-03) ^b	0.04	0.27	0.05	
Gas - regenerative (SCC 3-05-012-01)	10	5	0.25	
Gas - recuperative (SCC 3-05-012-02)	10	1.7	0.25	
Gas - unit melter (SCC 3-05-012-07)	0.6	0.3	0.25	
Glass furnace - textile				
Gas - recuperative (SCC 3-05-012-12) ^b	3	20	0.5	
Gas - regenerative (SCC 3-05-012-11)	30	20	1	
Gas - unit melter (SCC 3-05-012-13)	ND	20	0.9	
Forming - wool				
Flame attenuation (SCC 3-05-012-08) ^b	NA	NA	NA	
Forming - textile (SCC 3-05-012-14) ^b	NA	NA	NA	
Oven curing - wool				
Flame attenuation (SCC 3-05-012-09) ^b	ND	2	3.5	
Oven curing and cooling - textile (SCC 3-05-012-15) ^b	NA	2.6	1.5	

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data.

NA = not applicable.^b Reference 5.

Table 11.13-5 (Metric Units). EMISSION FACTORS FOR GLASS FIBER MANUFACTURING^a

EMISSION FACTOR RATING: B

	VOC	Phenolics	Phenol	Formaldehyde	Fluorides
Source	kg/Mg Of Material Processed				
Glass furnace - wool			[1
Electric (SCC 3-05-012-03) ^b	ND	ND	ND	ND	0.001
Gas - regenerative (SCC 3-05-012-01)	ND	ND	ND	ND	0.06
Gas - recuperative (SCC 3-05-012-02)	ND	ND	ND	ND	0.06
Gas - unit melter (SCC 3-05-012-07)	ND	ND	ND	ND I	0.06
Glass furnace - textile ^b		1 !	1	! '	
Gas - recuperative (SCC 3-05-012-12)	ND	ND	ND	ND	1
Gas - regenerative (SCC 3-05-012-11)	ND	ND	ND	ND	1
Gas - unit melter (SCC 3-05-012-13)	ND	ND	ND	ND	1
Forming - wool	1	1	l	1	1
Flame attenuation (SCC 3-05-012-08) ^v	0.15	ND	ND	ND	ND
Forming - textile (SCC 3-05-012-14) ^b	Neg	ND	ND	ND	NA
Oven curing - wool	-	1 '	1	'	
Flame attenuation (SCC 3-05-012-09) ^b	3.5	ND	ND	ND	ND
Oven curing and cooling - textile (SCC 3-05-012-15) ^b	Neg	ND	ND	ND	ND
Rotary spin wool glass fiber manufacturing (SCC 3-05-012-04) ^c					
R-19	ND	3.21	0.96	0.75	ND
R-11	ND	6.21	0.92	1.23	ND
Ductboard	ND	10.66	3.84	1.80	ND
Heavy density	ND /	0.88	0.53	0.43	ND

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data. NA = not applicable. Neg = negligible. ^b Reference 5.

^c Reference 4.

9/85 (Reformatted 1/95)
Table 11.13-6 (English Units). EMISSION FACTORS FOR GLASS FIBER MANUFACTURING^a

EMISSION FACTOR RATING: B

	VOC	Phenolics	Phenol	Formaldehyde	Fluorides
	lb/ton Of	lb/ton Of	lb/ton Of	lb/ton Of	lb/ton Of
	Material	Material	Material	Material	Material
Source	Processea	Processea	Processea	Processed	Processed
Glass furnace - wool					
Electric (SCC 3-05-012-03) ^b	ND	ND	ND	ND	0.002
Gas - regenerative (SC 3-05-012-01)	ND	ND	ND	ND	0.12
Gas - recuperative (SCC 3-05-012-02)	ND	ND	ND	ND	0.11
Gas - unit melter (SCC 3-05-012-07)	ND	ND	ND	ND	0.12
Glass furnace - textile ^b					
Gas - recuperative (SCC 3-05-021-12)	ND	ND	ND	ND	2
Gas - regenerative (SCC 3-05-021-11)	ND	ND	ND	ND	2
Gas - unit melter (SCC 3-05-021-13)	ND	ND	ND	ND	2
Forming - wool				1	
Flame attenuation (SCC 3-05-021-08) ^b	0.3	ND	ND	ND	ND
Forming - textile (SCC 3-05-021-14) ^b	Neg	ND	ND	ND	NA
Oven curing - wool					
Flame attenuation (SCC 3-05-021-09) ^b	7	ND	ND	ND	ND
Oven curing and cooling - textile (SCC 3-05-021-15) ^b	Neg	ND	ND	ND	ND
Rotary spin wool glass fiber manufacturing (SCC 3-05-021-04) ^f					
Ř-19	ND	6.92	1.92	1.50	ND
R-11	ND	12.41	1.84	2.46	ND
Ductboard	ND	21.31	7.68	3.61	ND
Heavy duty	ND	1.74	1.04	0.85	ND

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data. NA = not applicable. Neg = negligible.
 ^b Reference 5.
 ^c Reference 4.

Particulate matter is the principal pollutant that has been identified and measured at wool fiberglass insulation manufacturing facilities. It was known that some fraction of the PM emissions results from condensation of organic compounds used in the binder. Therefore, in evaluating emissions and control device performance for this source, a sampling method, EPA Reference Method 5E, was used that permitted collection and measurement of both solid particles and condensed PM.

Tests were performed during the production of R-11 building insulation, R-19 building insulation, ductboard, and heavy-density insulation. These products, which account for 91 percent of industry production, had densities ranging from 9.1 to 12.3 kilograms per cubic meter (kg/m^3) (0.57 to 0.77 pounds per cubic foot [lb/ft³]) for R-11, 8.2 to 9.3 kg/m³ (0.51 to 0.58 lb/ft³) for R-19, and 54.5 to 65.7 kg/m³ (3.4 to 4.1 lb/ft³) for ductboard. The heavy-density insulation had a density of 118.5 kg/m³ (7.4 lb/ft³). (The remaining 9 percent of industry wool fiberglass production is a variety of specialty products for which qualitative and quantitative information is not available.) The loss on ignition (LOI) of the product is a measure of the amount of binder present. The LOI values ranged from 3.9 to 6.5 percent, 4.5 to 4.6 percent, and 14.7 to 17.3 percent for R-11, R-19, and ductboard, respectively. The LOI for heavy-density insulation is 10.6 percent. A production line may be used to manufacture more than one of these product types because the processes involved do not differ. Although the data base did not show sufficient differences in mass emission levels to establish separate emission standards for each product, the uncontrolled emission factors are sufficiently different to warrant their segregation for AP-42.

The level of emissions control found in the wool fiberglass insulation manufacturing industry ranges from uncontrolled to control of forming, curing, and cooling emissions from a line. The exhausts from these process operations may be controlled separately or in combination. Control technologies currently used by the industry include wet ESPs, low- and high-pressure-drop wet scrubbers, low- and high-temperature thermal incinerators, high-velocity air filters, and process modifications. These added control technologies are available to all firms in the industry, but the process modifications used in this industry are considered confidential. Wet ESPs are considered to be best demonstrated technology for the control of emissions from wool fiberglass insulation manufacturing lines. Therefore, it is expected that most new facilities will be controlled in this manner.

Textile Fiber Forming And Finishing -

Emissions from the forming and finishing processes include glass fiber particles, resin particles, hydrocarbons (primarily phenols and aldehydes), and combustion products from dryers and ovens. Emissions are usually lower in the textile fiber glass process than in the wool fiberglass process because of lower turbulence in the forming step, roller application of coatings, and use of much less coating per ton of fiber produced.

References For Section 11.13

- 1. J. R. Schorr et al., Source Assessment: Pressed And Blown Glass Manufacturing Plants, EPA-600/2-77-005, U. S. Environmental Protection Agency, Cincinnati, OH, January 1977.
- 2. Annual Book Of ASTM Standards, Part 18, ASTM Standard C167-64 (Reapproved 1979), American Society For Testing And Materials, Philadelphia, PA.
- 3. Standard Of Performance For Wool Fiberglass Insulation Manufacturing Plants, 50 FR 7700, February 25, 1985.

- 4. Wool Fiberglass Insulation Manufacturing Industry: Background Information For Proposed Standards, EPA-450/3-83-022a, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1983.
- 5. Screening Study to Determine Need for Standards of Performance for New Sources in the Fiber Glass Manufacturing Industry-Draft, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1976.

11.14 Frit Manufacturing

11.14.1 Process Description¹⁻⁶

Frit is a homogeneous melted mixture of inorganic materials that is used in enameling iron and steel and in glazing porcelain and pottery. Frit renders soluble and hazardous compounds inert by combining them with silica and other oxides. Frit also is used in bonding grinding wheels, to lower vitrification temperatures, and as a lubricant in steel casting and metal extrusion. The six digit Source Classification Code (SCC) for frit manufacturing is 3-05-013.

Frit is prepared by fusing a variety of minerals in a furnace and then rapidly quenching the molten material. The constituents of the feed material depend on whether the frit is to be used as a ground coat or as a cover coat. For cover coats, the primary constituents of the raw material charge include silica, fluorspar, soda ash, borax, feldspar, zircon, aluminum oxide, lithium carbonate, magnesium carbonate, and titanium oxide. The constituents of the charge for a ground coat include the same compounds plus smaller amounts of metal oxides such as cobalt oxide, nickel oxide, copper oxide, and manganese oxide.

To begin the process, raw materials are shipped to the manufacturing facility by truck or rail and are stored in bins. Next, the raw materials are carefully weighed in the correct proportions. The raw batch then is dry mixed and transferred to a hopper prior to being fed into the smelting furnace. Although pot furnaces, hearth furnaces, and rotary furnaces have been used to produce frit in batch operations, most frit is now produced in continuous smelting furnaces. Depending on the application, frit smelting furnaces operate at temperatures of 930° to 1480° C (1700° to 2700° F). If a continuous furnace is used, the mixed charge is fed by screw conveyor directly into the furnace. Continuous furnaces operate at temperatures of 1090° to 1430° C (2000° to 2600° F). When smelting is complete, the molten material is passed between water-cooled metal rollers that limit the thickness of the material, and then it is quenched with a water spray that shatters the material into small glass particles called frit.

After quenching, the frit is milled by either wet or dry grinding. If the latter, the frit is dried before grinding. Frit produced in continuous furnaces generally can be ground without drying, and it is sometimes packaged for shipping without further processing. Wet milling of frit is no longer common. However, if the frit is wet-milled, it can be charged directly to the grinding mill without drying. Rotary dryers are the devices most commonly used for drying frit. Drying tables and stationary dryers also have been used. After drying, magnetic separation may be used to remove iron-bearing material. The frit is finely ground in a ball mill, into which clays and other electrolytes may be added, and then the product is screened and stored. The frit product then is transported to on-site ceramic manufacturing processes or is prepared for shipping. In recent years, the electrostatic deposition spray method has become the preferred method of applying frit glaze to surfaces. Frit that is to be applied in that manner is mixed during the grinding step with an organic silicon encapsulating agent, rather than with clay and electrolytes. Figure 11.14-1 presents a process flow diagram for frit manufacturing.

11.14.2 Emissions And Controls^{1,7-10}

Significant emissions of particulate matter (PM) and PM less than 10 micrometers (PM-10) are created by the frit smelting operation in the form of dust and fumes. These emissions consist primarily of condensed metallic oxide fumes that have volatilized from the molten charge. The emissions also contain mineral dust and sometimes hydrogen fluoride. Emissions from furnaces also include products of combustion, such as carbon monoxide (CO), carbon dioxide (CO₂), and nitrogen oxides (NO_x). Sulfur oxides (SO_x) also may be emitted, but they generally are absorbed by the molten material to form an



Figure 11.14-1 Process flow diagram for frit manufacturing. (Source Classification Code in parentheses)

EMISSION FACTORS

immiscible sulphate that is eliminated in the quenching operation. Particulate matter also is emitted from drying, grinding, and materials handling and transfer operations

Emissions from the furnace can be minimized by careful control of the rate and duration of raw material heating, to prevent volatilization of the more fusible charge materials. Emissions from rotary furnaces also can be reduced with careful control of the rotation speed, to prevent excessive dust carryover. Venturi scrubbers and fabric filters are the devices most commonly used to control emissions from frit smelting furnaces, and fabric filters are commonly used to control emissions from grinding operations. No information is available on the type of emission controls used on quenching, drying, and materials handling and transfer operations.

Table 11.14-1 presents emission factors for filterable PM, CO, NO_{∞} and CO₂ emissions from frit manufacturing. Table 11.14-2 presents emission factors for other pollutant emissions from frit manufacturing.

11.14.3 Updates Since the Fifth Edition

The Fifth Edition was released in January 1995. A complete revision of this section was completed on 11/95. The emission factor for NOx for Smelting Furnace was revised on 6/97 based upon a review of the production information that was provided by the manufacturing facility.

Table 11.14-1. EMISSION FACTORS FOR FRIT MANUFACTURING^a

Source	Filterable PM ^b	CO	NO _x	CO ₂
Smelting furnace (SCC 3-05-013-05,06)	16°	4.8°	16 ^d	1,300°
Smelting furnace with venturi scrubber (SCC 3-05-013-05,06)	1.8 ^f	g	g	g
Smelting furnace with fabric filter (SCC 3-05-013-05,-06)	0.020 ^d	g	g	g

EMISSION FACTOR RATING: E

^a Factors represent uncontrolled emissions unless otherwise noted. Emission factor units are lb/ton of feed material. ND = no data. SCC = Source Classification Code. To convert from lb/ton to kg/Mg, multiply by 0.5.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

^c Reference 1.

^d Reference 10.

* Reference 7-10.

^f References 7-9. EMISSION FACTOR RATING: D

⁸ See factor for uncontrolled emissions.

Table 11.14-2. EMISSION FACTORS FOR FRIT MANUFACTURING--FLUORIDES AND METALS[®]

EMISSION	FACTOR	RATING:	Ε
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	Pollutant	Emission factor, lb/ton
Smelting furnace with fabric filter (SCC 3-05-013-05,-06)	fluorides	0.88
	barium	2.8 x 10 ⁻⁵
	chromium	1.4 x 10 ⁻⁵
	cobalt	4.3 x 10 ⁻⁶
	copper	1.9 x 10 ⁻⁵
	lead	9.6 x 10 ⁻⁶
	manganese	1.4 x 10 ⁻⁵
	nickel	1.6 x 10 ⁻⁵
	zinc	1.2 x 10 ⁻⁴

*Reference 10. Factor units are lb/ton of material feed.

SCC = Source Classification Code. To convert from lb/ton to kg/Mg, multiply by 0.5.

References For Section 11.14

- 1. J. L. Spinks, "Frit Smelters", *Air Pollution Engineering Manual*, Danielson, J. A. (ed.), PHS Publication Number 999-AP-40, U. S. Department Of Health, Education, And Welfare, Cincinnati, OH, 1967.
- 2. "Materials Handbook", Ceramic Industry, Troy, MI, January 1994.
- 3. Andrew I. Andrews, Enamels: The Preparation, Application, And Properties Of Vitreous Enamels, Twin City Printing Company, Champaign, IL, 1935.
- 4. Written communication from David Ousley, Alabama Department of Environmental Management, Montgomery, AL, to Richard Marinshaw, Midwest Research Institute, Cary, NC, April 1, 1993.
- 5. Written communication from Bruce Larson, Chi-Vit Corporation, Urbana, OH, to David Ousley, Alabama Department Of Environment Management, Montgomery, AL, October 10, 1994.
- 6. Written communication from John Jozefowski, Miles Industrial Chemicals Division, Baltimore, MD, to Ronald E. Myers, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 22, 1994.

- 7. Particulate Emissions Test Results, No. 2 North Stack, Chi-Vit Corporation, Leesburg, Alabama, ATC, Inc. Auburn, AL, May 1987.
- 8. No. 1 South Stack Particulate Test Report, Chi-Vit Corporation, Leesburg, Alabama, April 1989, ATC, Inc., Auburn, AL, May 1989.
- 9. Frit Unit No. 2, Scrubber No. 2, Particulate Emission Test Report, Chi-Vit Corporation, Leesburg, Alabama, April 1991, ATC, Inc., Auburn, AL, April 1991.
- 10. Diagnostic Test, Dry Gas Cleaning Exhauster Stack, Miles, Inc., International Technology Corporation, Monroeville, PA, February 1994.

11.15 Glass Manufacturing

11.15.1 General¹⁻⁵

Commercially produced glass can be classified as soda-lime, lead, fused silica, borosilicate, or 96 percent silica. Soda-lime glass, since it constitutes 77 percent of total glass production, is discussed here. Soda-lime glass consists of sand, limestone, soda ash, and cullet (broken glass). The manufacture of such glass is in four phases: (1) preparation of raw material, (2) melting in a furnace, (3) forming and (4) finishing. Figure 11.15-1 is a diagram for typical glass manufacturing.

The products of this industry are flat glass, container glass, and pressed and blown glass. The procedures for manufacturing glass are the same for all products except forming and finishing. Container glass and pressed and blown glass, 51 and 25 percent respectively of total soda-lime glass production, use pressing, blowing or pressing and blowing to form the desired product. Flat glass, which is the remainder, is formed by float, drawing, or rolling processes.

As the sand, limestone, and soda ash raw materials are received, they are crushed and stored in separate elevated bins. These materials are then transferred through a gravity feed system to a weigher and mixer, where the material is mixed with cullet to ensure homogeneous melting. The mixture is conveyed to a batch storage bin where it is held until dropped into the feeder to the melting furnace. All equipment used in handling and preparing the raw material is housed separately from the furnace and is usually referred to as the batch plant. Figure 11.15-2 is a flow diagram of a typical batch plant.

The furnace most commonly used is a continuous regenerative furnace capable of producing between 45 and 272 megagrams (Mg) (50 and 300 tons) of glass per day. A furnace may have either side or end ports that connect brick checkers to the inside of the melter. The purpose of brick checkers (Figure 11.15-3 and Figure 11.15-4) is to conserve fuel by collecting furnace exhaust gas heat that, when the air flow is reversed, is used to preheat the furnace combustion air. As material enters the melting furnace through the feeder, it floats on the top of the molten glass already in the furnace. As it melts, it passes to the front of the melter and eventually flows through a throat leading to the refiner. In the refiner, the molten glass is heat conditioned for delivery to the forming process. Figures 11.15-3 and 11.15-4 show side port and end port regenerative furnaces.

After refining, the molten glass leaves the furnace through forehearths (except in the float process, with molten glass moving directly to the tin bath) and goes to be shaped by pressing, blowing, pressing and blowing, drawing, rolling, or floating to produce the desired product. Pressing and blowing are performed mechanically, using blank molds and glass cut into sections (gobs) by a set of shears. In the drawing process, molten glass is drawn upward in a sheet through rollers, with thickness of the sheet determined by the speed of the draw and the configuration of the draw bar. The rolling process is similar to the drawing process except that the glass is drawn horizontally on plain or patterned rollers and, for plate glass, requires grinding and polishing. The float process is different, having a molten tin bath over which the glass is drawn and formed into a finely finished surface requiring no grinding or polishing. The end product undergoes finishing (decorating or coating) and annealing (removing unwanted stress areas in the glass) as required, and is then inspected and prepared for shipment to market. Any damaged or undesirable glass is transferred back to the batch plant to be used as cullet.



Figure 11.15-1. Typical glass manufacturing process.



Figure 11.15-2. General diagram of a batch plant.



Figure 11.15-3. Side port continuous regenerative furnace.



Figure 11.15-4. End port continuous regenerative furnace.

Mineral Products Industry

11.15.2 Emissions And Controls¹⁻⁵

The main pollutant emitted by the batch plant is particulates in the form of dust. This can be controlled with 99 to 100 percent efficiency by enclosing all possible dust sources and using baghouses or cloth filters. Another way to control dust emissions, also with an efficiency approaching 100 percent, is to treat the batch to reduce the amount of fine particles present, by presintering, briquetting, pelletizing, or liquid alkali treatment.

The melting furnace contributes over 99 percent of the total emissions from a glass plant, both particulates and gaseous pollutants. Particulates result from volatilization of materials in the melt that combine with gases and form condensates. These either are collected in the checker work and gas passages or are emitted to the atmosphere. Serious problems arise when the checkers are not properly cleaned in that slag can form, clog the passages, and eventually deteriorate the condition and efficiency of the furnace. Nitrogen oxides form when nitrogen and oxygen react in the high temperatures of the furnace. Sulfur oxides result from the decomposition of the sulfates in the batch and sulfur in the fuel. Proper maintenance and firing of the furnace can control emissions and also add to the efficiency of the furnace and reduce operational costs. Low-pressure wet centrifugal scrubbers have been used to control particulate and sulfur oxides, but their inefficiency (approximately 50 percent) indicates their inability to collect particulates of submicrometer size. High-energy venturi scrubbers are approximately 95 percent effective in reducing particulate and sulfur oxide emissions. Their effect on nitrogen oxide emissions is unknown. Baghouses, with up to 99 percent particulate collection efficiency, have been used on small regenerative furnaces, but fabric corrosion requires careful temperature control. Electrostatic precipitators have an efficiency of up to 99 percent in the collection of particulates. Tables 11.15-1 and 11.15-2 list controlled and uncontrolled emission factors for glass manufacturing. Table 11.15-3 presents particle size distributions and corresponding emission factors for uncontrolled and controlled glass melting furnaces, and these are depicted in Figure 11.15-5.

Emissions from the forming and finishing phases depend upon the type of glass being manufactured. For container, press, and blow machines, the majority of emissions results from the gob coming into contact with the machine lubricant. Emissions, in the form of a dense white cloud that can exceed 40 percent opacity, are generated by flash vaporization of hydrocarbon greases and oils. Grease and oil lubricants are being replaced by silicone emulsions and water soluble oils, which may virtually eliminate this smoke. For flat glass, the only contributor to air pollutant emissions is gas combustion in the annealing lehr (oven), which is totally enclosed except for product entry and exit openings. Since emissions are small and operational procedures are efficient, no controls are used on flat glass processes.

EMISSION FACTORS

Table 11.15-1 (Metric And English Units). PARTICULATE, SULFUR OXIDES, AND NITROGEN OXIDES EMISSION FACTORS FOR GLASS MANUFACTURING^a

EMISSION FACTOR RATING: B

	Particulate		Sulfur Oxides		Nitrogen Oxides	
Process	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Raw materials handling ^b (all types of glass)	Neg	Neg	0	0	0	0
Melting furnace ^c						
Container						
Uncontrolled	0.7	1.4	1.7	3.4	3.1	6.2
	(0.4 - 0.9)	(0.9 - 1.9)	(1.0 - 2.4)	(2.0 - 4.8)	(1.6 - 4.5)	(3.3 - 9.1)
w/low-energy scrubber ^d	0.4	0.7	0.9	1.7	3.1	6.2
w/venturi scrubber ^e	< 0.1	0.1	0.1	0.2	3.1	6.2
w/baghouse ^f	Neg	Neg	1.7	3.4	3.1	6.2
w/electrostatic precipitator ^g	Neg	Neg	1.7	3.4	3.1	6.2
Flat						
Uncontrolled	1.0	2.0	1.5	3.0	4.0	8.0
	(0.4 - 1.0)	(0.8 - 3.2)	(1.1 - 1.9)	(2.2 - 3.8)	(2.8 - 5.2)	(5.6 - 10.4)
w/low-energy scrubber ^d	0.5	1.0	0.8	1.5	4.0	8.0
w/venturi scrubber ^e	Neg	Neg	0.1	0.2	4.0	8.0
w/baghouse ^f	Neg	Neg	1.5	3.0	4.0	8.0
w/electrostatic precipitator ^g	Neg	Neg	1.5	3.0	4.0	8.0
Pressed and blown						
Uncontrolled	8.4	17.4	2.8	5.6	4.3	8.5
	(0.5 - 12.6)	(1.0 - 25.1)	(0.5 - 5.4)	(1.1 - 10.9)	(0.4 - 10.0)	(0.8 - 20.0)

	Parti	culate	Sulfur	Oxides	Nitroge	n Oxides
Process	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
w/low-energy scrubber ^d	4.2	8.4	1.3	2.7	4.3	8.5
w/venturi scrubber ^e	0.5	0.9	0.1	0.3	4.3	8.5
w/baghouse ^f	0.1	0.2	2.8	5.6	4.3	8.5
w/electrostatic precipitator ^g	0.1	0.2	2.8	5.6	4.3	8.5
Forming and finishing						
Container ^{h,j}	Neg	Neg	Neg	Neg	Neg	Neg
Flat	Neg	Neg	Neg	Neg	Neg	Neg
Pressed and blown ^{h j}	Neg	Neg	Neg	Neg	Neg	Neg
Lead glass manufacturing, all processes ^k	ND	ND	ND	ND	ND	ND

Table 11.15-1 (cont.).

^a Reference 2-3,5. ND = no data. Neg = negligible. Ranges in parentheses, where available. Expressed as kg/Mg (lb/ton) of glass produced.

^b Not separated into types of glass produced, since batch preparation is the same for all types. Particulate emissions are negligible because almost all plants utilize some form of control (i. e., baghouses, scrubbers, centrifugal collectors).

^c Control efficiencies for the various devices are applied only to the average emission factor.

^d Approximately 52% efficiency in reducing particulate and sulfur oxides emissions. Effect on nitrogen oxides is unknown.

^e Approximately 95% efficiency in reducing particulate and sulfur oxide emissions. Effect on nitrogen oxides is unknown.

^f Approximately 99% efficiency in reducing particulate emissions.

^g Calculated using data for furnaces melting soda lime and lead glasses. No data available for borosilicate or opal glasses.

^h Organic emissions are from decorating process. Can be controlled by incineration, absorption, or condensation, but efficiencies are not known.

^j For container and pressed and blown glass, tin chloride, hydrated tin chloride and hydrogen chloride are also emitted during surface treatment process at a rate of <0.1 kg/Mg (0.2 lb/ton) each.

^k References 6-7. Particulate containing 23% lead.

Table 11.15-2 (Metric And English Units).VOC, CARBON MONOXIDE, AND LEAD EMISSION FACTORS
FOR GLASS MANUFACTURING^a

EMISSION FACTOR RATING: B

	V	OC	Carbon N	Monoxide	L	ead
Process	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Raw materials handling ^b (all types of glass)	0	0	0	0	ND	ND
Melting furnace ^c						
Container						
Uncontrolled	0.1	0.2	0.1	0.2	ND	ND
	(0 - 0.2)	(0 - 0.4)	(0 - 0.2)	(0 - 0.5)		
w/low-energy scrubber ^d	0.1	0.2	0.1	0.2	ND	ND
w/venturi scrubber ^e	0.1	0.2	0.1	0.2	ND	ND
w/baghouse ^f	0.1	0.2	0.1	0.2	ND	ND
w/electrostatic precipitator ^g	0.1	0.2	0.1	0.2	ND	ND
Flat						
Uncontrolled	< 0.1	< 0.1	< 0.1	< 0.1	ND	ND
w/low-energy scrubber ^d	< 0.1	< 0.1	< 0.1	< 0.1	ND	ND
w/venturi scrubber ^e	< 0.1	< 0.1	< 0.1	< 0.1	ND	ND
w/baghouse ^f	< 0.1	< 0.1	< 0.1	< 0.1	ND	ND
w/electrostatic precipitator ^g	< 0.1	< 0.1	< 0.1	< 0.1	ND	ND
Pressed and blown						
Uncontrolled	0.2	0.3	0.1	0.2	ND	ND
	(0.1 - 0.3)	(0.1 - 1.0)	(0.1 - 0.2)	(0.1 - 0.3)		

]
EMISSION F	
Ä	
TOF	
S	b

	V	D <u>C</u>	Carbon M	Aonoxide	L	ead
Process	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
w/low-energy scrubber ^d	0.2	0.3	0.1	0.2	ND	ND
w/venturi scrubber ^e	0.2	0.3	0.1	0.2	ND	ND
w/baghouse ^f	0.2	0.3	0.1	0.2	ND	ND
w/electrostatic precipitator ^g	0.2	0.3	0.1	0.2	ND	ND
Forming and finishing						
Container ^{h,j}	4.4	8.7	Neg	Neg	ND	ND
Flat	Neg	Neg	Neg	Neg	ND	ND
Pressed and blown ^{h,j}	4.5	9.0	Neg	Neg	ND	ND
Lead glass manufacturing, all processes ^k	ND	ND	ND	ND	2.5	5

Table 11.15-2 (cont.).

^a Reference 2-3,5. ND = no data. Neg = negligible. Ranges in parentheses, where available. Expressed as kg/Mg (lb/ton) of glass produced.

^b Not separated into types of glass produced, since batch preparation is the same for all types. Particulate emissions are negligible because almost all plants utilize some form of control (i. e., baghouses, scrubbers, centrifugal collectors).

^c Control efficiencies for the various devices are applied only to the average emission factor.

^d Approximately 52% efficiency in reducing particulate and sulfur oxides emissions. Effect on nitrogen oxides is unknown.

^e Approximately 95% efficiency in reducing particulate and sulfur oxide emissions. Effect on nitrogen oxides is unknown.

^f Approximately 99% efficiency in reducing particulate emissions.

^g Calculated using data for furnaces melting soda lime and lead glasses. No data are available for borosilicate or opal glasses.

^h Organic emissions are from decorating process. Can be controlled by incineration, absorption or condensation, but efficiencies are not known.

^j For container and pressed and blown glass, tin chloride, hydrated tin chloride and hydrogen chloride are also emitted during surface treatment process at a rate of <0.1 kg/Mg (0.2 lb/ton) each.

^k References 6-7. Particulate containing 23% lead.



Figure 11.15-5. Particle size distributions and emission factors for glass melting furnace exhaust.

Table 11.15-3 (Metric Units). PARTICLE SIZE DISTRIBUTIONS AND EMISSION FACTORS FOR UNCONTROLLED AND CONTROLLED MELTING FURNACES IN GLASS MANUFACTURING^a

A gradunamia Dartiala	Particle Size	e Distribution ^b	Size-Specific Emission Factor, kg/Mg ^c
Diameter, μm	Uncontrolled	ESP Controlled ^d	Uncontrolled
2.5	91	53	0.64
6.0	93	66	0.65
10	95	75	0.66

^a References 8-11.

^b Cumulative weight % of particles < corresponding particle size.

^c Based on mass particulate emission factor of 0.7 kg/Mg glass produced, from Table 11.15-1. Sizespecific emission factor = mass particulate emission factor x particle size distribution, %/100. After ESP control, size-specific emission factors are negligible.

^d References 8-9. Based on a single test.

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11.16 Gypsum Manufacturing

11.16.1 Process Description¹⁻²

Gypsum is calcium sulfate dihydrate (CaSO₄ \cdot 2H₂O), a white or gray naturally occurring mineral. Raw gypsum ore is processed into a variety of products such as a portland cement additive, soil conditioner, industrial and building plasters, and gypsum wallboard. To produce plasters or wallboard, gypsum must be partially dehydrated or calcined to produce calcium sulfate hemihydrate (CaSO₄ \cdot ½H₂O), commonly called stucco.

A flow diagram for a typical gypsum process producing both crude and finished gypsum products is shown in Figure 11.16-1. In this process gypsum is crushed, dried, ground, and calcined. Not all of the operations shown in Figure 11.16-1 are performed at all gypsum plants. Some plants produce only wallboard, and many plants do not produce soil conditioner.

Gypsum ore, from quarries and underground mines, is crushed and stockpiled near a plant. As needed, the stockpiled ore is further crushed and screened to about 50 millimeters (2 inches) in diameter. If the moisture content of the mined ore is greater than about 0.5 weight percent, the ore must be dried in a rotary dryer or a heated roller mill. Ore dried in a rotary dryer is conveyed to a roller mill, where it is ground to the extent that 90 percent of it is less 149 micrometers (μ m) (100 mesh). The ground gypsum exits the mill in a gas stream and is collected in a product cyclone. Ore is sometimes dried in the roller mill by heating the gas stream, so that drying and grinding are accomplished simultaneously and no rotary dryer is needed. The finely ground gypsum ore is known as landplaster, which may be used as a soil conditioner.

In most plants, landplaster is fed to kettle calciners or flash calciners, where it is heated to remove three-quarters of the chemically bound water to form stucco. Calcination occurs at approximately 120 to 150°C (250 to 300°F), and 0.908 megagrams (Mg) (1 ton) of gypsum calcines to about 0.77 Mg (0.85 ton) of stucco.

In kettle calciners, the gypsum is indirectly heated by hot combustion gas passed through flues in the kettle, and the stucco product is discharged into a "hot pit" located below the kettle. Kettle calciners may be operated in either batch or continuous mode. In flash calciners, the gypsum is directly contacted with hot gases, and the stucco product is collected at the bottom of the calciner.

At some gypsum plants, drying, grinding, and calcining are performed in heated impact mills. In these mills hot gas contacts gypsum as it is ground. The gas dries and calcines the ore and then conveys the stucco to a product cyclone for collection. The use of heated impact mills eliminates the need for rotary dryers, calciners, and roller mills.

Gypsum and stucco are usually transferred from one process to another by means of screw conveyors or bucket elevators. Storage bins or silos are normally located downstream of roller mills and calciners but may also be used elsewhere.



Figure 11.16-1. Overall process flow diagram for gypsum processing.²

EMISSION FACTORS

In the manufacture of plasters, stucco is ground further in a tube or ball mill and then batchmixed with retarders and stabilizers to produce plasters with specific setting rates. The thoroughly mixed plaster is fed continuously from intermediate storage bins to a bagging operation.

In the manufacture of wallboard, stucco from storage is first mixed with dry additives such as perlite, starch, fiberglass, or vermiculite. This dry mix is combined with water, soap foam, accelerators and shredded paper, or pulpwood in a pin mixer at the head of a board forming line. The slurry is then spread between 2 paper sheets that serve as a mold. The edges of the paper are scored, and sometimes chamfered, to allow precise folding of the paper to form the edges of the board. As the wet board travels the length of a conveying line, the calcium sulfate hemihydrate combines with the water in the slurry to form solid calcium sulfate dihydrate, or gypsum, resulting in rigid board. The board is rough-cut to length, and it enters a multideck kiln dryer, where it is dried by direct contact with hot combustion gases or by indirect steam heating. The dried board is conveyed to the board end sawing area and is trimmed and bundled for shipment.

11.16.2 Emissions And Controls^{2,7}

Potential emission sources in gypsum processing plants are shown in Figure 11.16-1. While particulate matter (PM) is the dominant pollutant in gypsum processing plants, several sources may emit gaseous pollutants also. The major sources of PM emissions include rotary ore dryers, grinding mills, calciners, and board end sawing operations. Particulate matter emission factors for these operations are shown in Table 11.16-1 and 11.16-2. In addition, emission factors for PM less than or equal to 10 μ m in aerodynamic diameter (PM-10) emissions from selected processes are presented in Tables 11.16-1 and 11.16-2. All of these factors are based on output production rates. Particle size data for ore dryers, calciners, and board end sawing operations are shown in Tables 11.16-2 and 11.16-3.

The uncontrolled emission factors presented in Table 11.16-1 and 11.16-2 represent the process dust entering the emission control device. It is important to note that emission control devices are frequently needed to collect the product from some gypsum processes and, thus, are commonly thought of by the industry as process equipment and not as added control devices.

Emissions sources in gypsum plants are most often controlled with fabric filters. These sources include:

- rotary ore dryers (SCC 3-05-015-01)	- board end sawing (SCC 3-05-015-21,-22)
- roller mills (SCC 3-05-015-02)	- scoring and chamfering (SCC 3-05-015)
- impact mills (SCC 3-05-015-13)	- plaster mixing and bagging (SCC 3-05-015-16,-17)
- kettle calciners (SCC 3-05-015-11)	- conveying systems (SCC 3-05-015-04)
- flash calciners (SCC 3-05-015-12)	- storage bins (SCC 3-05-015-09,-10,-14)

Uncontrolled emissions from scoring and chamfering, plaster mixing and bagging, conveying systems, and storage bins are not well quantified.

Emissions from some gypsum sources are also controlled with electrostatic precipitators (ESP). These sources include rotary ore dryers, roller mills, kettle calciners, and conveying systems. Although rotary ore dryers may be controlled separately, emissions from roller mills and conveying systems are usually controlled jointly with kettle calciner emissions. Moisture in the kettle calciner exit gas improves the ESP performance by lowering the resistivity of the dust.

Table 11.16-1 (Metric Units). EMISSION FACTORS FOR GYPSUM PROCESSING^a

Process	Filterable PM ^b	PM-10	CO ₂ °
Crushers, screens, stockpiles, and roads (SCC 3-05-015-05,-06,-07,-08)	d	d	NA
Rotary ore dryers (SCC 3-05-015-01)	0.0042(FFF) ^{1.7e}	0.00034(FFF) ^{1.7}	12 ^f
Rotary ore dryers w/fabric filters (SCC 3-05-015-01)	0.020 ^g	0.0052	NA
Roller mills w/cyclones (SCC 3-05-015-02)	1.3 ^h	ND	NA
Roller mills w/fabric filters (SCC 3-05-015-02)	0.060 ^h	ND	NA
Roller mill and kettle calciner w/electrostatic precipitators (SCC 3-05-015-02,-11)	0.050 ^{h.j}	ND	ND .
Continuous kettle calciners and hot pit (SCC 3-05-015-11)	21 ^k	13	ND
Continuous kettle calciners and hot pit w/fabric filters (SCC 3-05-015-11)	0.0030 ^k	ND	NA
Continuous kettle calciners w/cyclones and electrostatic precipitators (SCC 3-05-015-11)	0.050 ^k	ND	NA
Flash calciners (SCC 3-05-015-12)	19 ^m	7.2 ^m	55 ⁿ
Flash calciners w/fabric filters (SCC 3-05-015-12)	0.020 ^m	0.017 ^m	ND
Impact mills w/cyclones (SCC 3-05-015-13)	50 ^p	ND	NA
Impact mills w/fabric filters (SCC 3-05-015-13)	0.010 ^p	ND	NA
Board end sawing2.4-m boards (SCC 3-05-015-21)	0.040 ^q	ND	NA
Board end sawing3.7-m boards (SCC 3-05-015-22)	0.030 ^q	ND	NA
Board end sawing w/fabric filters 2.4-and 3.7-m boards (SCC 3-05-015-21,-22)	36 ^r	27 ^r	NA

EMISSION FACTOR RATING: D

^a Factors represent uncontrolled emissions unless otherwise specified. All emission factors are kg/Mg of output rate. SCC = Source Classification Code. NA = not applicable. ND = no data.
 ^b Filterable PM is that PM collected on or prior to an EPA Method 5 (or equivalent) sampling train.

Table 11.16-1 (cont.).

- ^c Typical pollution control devices generally have a negligible effect on CO₂ emissions.
- ^d Factors for these operations are in Sections 11.19 and 13.2.
- ^e References 3-4,8,11-12. Equation is for the emission rate upstream of any process cyclones and applies only to concurrent rotary ore dryers with flow rates of 7.5 cubic meters per second (m³/s) or less. FFF in the uncontrolled emission factor equation is "flow feed factor," the ratio of gas mass rate per unit dryer cross section area to the dry mass feed rate, in the following units: (kg/hr-m² of gas flow)/(Mg/hr dry feed). Measured uncontrolled emission factors for 4.2 and 5.7 m³/s range from 5 to 60 kg/Mg.
- ^f References 3-4.
- ^g References 3-4,8,11-12. Applies to rotary dryers with and without cyclones upstream of fabric filter.
- ^h References 11-14. Applies to both heated and unheated roller mills.
- ^j References 11-14. Factor is for combined emissions from roller mills and kettle calciners, based on the sum of the roller mill and kettle calciner output rates.
- ^k References 4-5,11,13-14. Emission factors based on the kettle and the hot pit do not apply to batch kettle calciners.
- ^m References 3,6,10.
- ⁿ References 3,6,9.
- ^p References 9,15. As used here, an impact mill is a process unit used to dry, grind, and calcine gypsum simultaneously.
- ^q References 4-5,16. Emission factor units = kg/m^2 . Based on 13-mm board thickness and 1.2 m board width. For other thicknesses, multiply the appropriate emission factor by 0.079 times board thickness in mm.
- ^r References 4-5,16. Emission factor units = $kg/10^6$ m².

Table 11.16-2 (English Units). EMISSION FACTORS FOR GYPSUM PROCESSING^a

Process	Filterable PM ^b	PM-10	. CO ₂ °
Crushers, screens, stockpiles, and roads (SCC 3-05-015-05,-06,-07,-08)	d	d	NA
Rotary ore dryers (SCC 3-05-015-01)	0.16(FFF) ^{1.77e}	0.013(FFF) ^{1.7}	23 ^f
Rotary ore dryers w/fabric filters (SCC 3-05-015-01)	0.040 ^g	0.010	NA
Roller mills w/cyclones (SCC 3-05-015-02)	2.6 ^h	ND	NA
Roller mills w/fabric filters (SCC 3-05-015-02)	0.12 ^h	ND	NA
Roller mill and kettle calciner w/electrostatic precipitators (SCC 3-05-015-02,-11)	0.090 ^{h,j}	ND	ND
Continuous kettle calciners and hot pit (SCC 3-05-015-11)	41 ^k	26	ND
Continuous kettle calciners and hot pit w/fabric filters (SCC 3-05-015-11)	0.0060 ^k	ND	NA
Continuous kettle calciners w/cyclones and electrostatic precipitators (SCC 3-05-015-11)	0.090 ^k	ND	NA
Flash calciners (SCC 3-05-015-12)	37 ^m	14 ^m	110 ⁿ
Flash calciners w/fabric filters (SCC 3-05-015-12)	0.040 ^m	0.034 ^m	ND
Impact mills w/cyclones (SCC 3-05-015-13)	100 ^p	ND	NA
Impact mills w/fabric filters (SCC 3-05-015-13)	0.020 ^p	ND	NA
Board end sawing8-ft boards (SCC 3-05-015-21)	0.80 ^q	ND	NA
Board end sawing12-ft boards (SCC 3-05-015-22)	0.50 ^q	ND	NA
Board end sawing w/fabric filters 8- and 12-ft boards (SCC 3-05-015-21,-22)	7.5 ^r	5.7 ^r	NA

EMISSION FACTOR RATING: D

.

^a Factors represent uncontrolled emissions unless otherwise specified. All emission factors are lb/ton of output rate. SCC = Source Classification Codes. NA = not applicable. ND = no data.

Table 11.16-2 (cont.).

- ^b Filterable PM is that particulate collected on or prior to an EPA Method 5 (or equivalent) sampling train.
- ^c Typical pollution control devices generally have a negligible effect on CO₂ emissions.
- ^d Factors for these operations are in Sections 8.19 and 13.2.
- ^e References 3-4,8,11-12. Equation is for the emission rate upstream of any process cyclones and applies only to concurrent rotary ore dryers with flow rates of 16,000 actual cubic feet per minute (acfm) or less. FFF in the uncontrolled emission factor equation is "flow feed factor," the ratio of gas mass rate per unit dryer cross section area to the dry mass feed rate, in the following units: (lb/hr-ft² of gas flow)/(ton/hr dry feed). Measured uncontrolled emission factors for 9,000 and 12,000 acfm range from 10 to 120 lb/ton.
- f References 3-4.
- ^g References 3-4,8,11-12. Applies to rotary dryers with and without cyclones upstream of fabric filter.
- ^h References 11-14. Applies to both heated and unheated roller mills.
- ^j References 11-14. Factor is for combined emissions from roller mills and kettle calciners, based on the sum of the roller mill and kettle calciner output rates.
- ^k References 4-5,11,13-14. Emission factors based on the kettle and the hot pit do not apply to batch kettle calciners.
- ^mReferences 3,6,10.
- ⁿ References 3,6,9.
- ^p References 9,15. As used here, an impact mill is a process unit used to dry, grind, and calcine gypsum simultaneously.
- ^q References 4-5,16. Emission factor units = lb/100 ft². Based on 1/2-in. board thickness and 4-ft board width. For other thicknesses, multiply the appropriate emission factor by 2 times board thickness in inches.
- ^r References 4-5,16. Emission factor units = $lb/10^6$ ft².

Table 11.16-3.SUMMARY OF PARTICLE SIZE DISTRIBUTION DATA FOR
UNCONTROLLED PM EMISSIONS FROM GYPSUM PROCESSING^a

		% Less Than Diameter		
Diameter (µm)	Rotary Ore Dryer ^b	Rotary Ore Dryer With Cyclone ^c	Continuous Kettle Calciner ^d	Flash Calciner ^e
2.0	1	12	17	10
10.0	8	45	63	38

EMISSION FACTOR RATING: D

^a Weight % given as filterable PM. Diameter is given as aerodynamic diameter, except for continuous kettle calciner, which is given as equivalent diameter, as determined by Bahco and Sedigraph analyses.

^b Reference 3.

^c Reference 4.

^d References 4-5.

^e References 3,6.

Table 11.16-4. SUMMARY OF PARTICLE SIZE DISTRIBUTION DATA FOR FABRIC FILTER-CONTROLLED PM EMISSIONS FROM GYPSUM MANUFACTURING^a

Diameter	Cumulative % Less Than Diameter							
μm)	Rotary Ore Dryer ^b	Flash Calciner ^c	Board End Sawing ^c					
2.0	9	52	49					
10.0	26	84	76					

EMISSION FACTOR RATING: D

^a Aerodynamic diameters, Andersen analysis.

^b Reference 3.

^c Reference 3,6.

Other sources of PM emissions in gypsum plants are primary and secondary crushers, screens, stockpiles, and roads. If quarrying is part of the mining operation, PM emissions may also result from drilling and blasting. Emission factors for some of these sources are presented in Sections 11.19 and 13.2. Gaseous emissions from gypsum processes result from fuel combustion and may include nitrogen oxides, sulfur oxides, carbon monoxide, and carbon dioxide (CO_2) . Processes using fuel include rotary ore dryers, heated roller mills, impact mills, calciners, and board drying kilns. Although some plants use residual fuel oil, the majority of the industry uses clean fuels such as natural gas or distillate fuel oil. Emissions from fuel combustion may be estimated using emission factors presented in Table 11.16-1.

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11.17 Lime Manufacturing

11.17.1 Process Description¹⁻⁵

Lime is the high-temperature product of the calcination of limestone. Although limestone deposits are found in every state, only a small portion is pure enough for industrial lime manufacturing. To be classified as limestone, the rock must contain at least 50 percent calcium carbonate. When the rock contains 30 to 45 percent magnesium carbonate, it is referred to as dolomite, or dolomitic limestone. Lime can also be produced from aragonite, chalk, coral, marble, and sea shells. The Standard Industry Classification (SIC) code for lime manufacturing is 3274. The six-digit Source Classification Code (SCC) for lime manufacturing is 3-05-016.

Lime is manufactured in various kinds of kilns by 1 of the following reactions:

 $CaCO_3 + heat \rightarrow CO_2 + CaO$ (high calcium lime) $CaCO_3 \cdot MgCO_3 + heat \rightarrow 2CO_2 + CaO \cdot MgO$ (dolomitic lime)

In some lime plants, the resulting lime is reacted (slaked) with water to form hydrated lime. The basic processes in the production of lime are: (1) quarrying raw limestone; (2) preparing limestone for the kilns by crushing and sizing; (3) calcining limestone; (4) processing the lime further by hydrating; and (5) miscellaneous transfer, storage, and handling operations. A generalized material flow diagram for a lime manufacturing plant is given in Figure 11.17-1. Note that some operations shown may not be performed in all plants.

The heart of a lime plant is the kiln. The prevalent type of kiln is the rotary kiln, accounting for about 90 percent of all lime production in the United States. This kiln is a long, cylindrical, slightly inclined, refractory-lined furnace, through which the limestone and hot combustion gases pass countercurrently. Coal, oil, and natural gas may all be fired in rotary kilns. Product coolers and kiln feed preheaters of various types are commonly used to recover heat from the hot lime product and hot exhaust gases, respectively.

The next most common type of kiln in the United States is the vertical, or shaft, kiln. This kiln can be described as an upright heavy steel cylinder lined with refractory material. The limestone is charged at the top and is calcined as it descends slowly to discharge at the bottom of the kiln. A primary advantage of vertical kilns over rotary kilns is higher average fuel efficiency. The primary disadvantages of vertical kilns are their relatively low production rates and the fact that coal cannot be used without degrading the quality of the lime produced. There have been few recent vertical kiln installations in the United States because of high product quality requirements.

Other, much less common, kiln types include rotary hearth and fluidized bed kilns. Both kiln types can achieve high production rates, but neither can operate with coal. The "calcimatic" kiln, or rotary hearth kiln, is a circular kiln with a slowly revolving doughnut-shaped hearth. In fluidized bed kilns, finely divided limestone is brought into contact with hot combustion air in a turbulent zone, usually above a perforated grate. Because of the amount of lime carryover into the exhaust gases, dust collection equipment must be installed on fluidized bed kilns for process economy.

Another alternative process that is beginning to emerge in the United States is the parallel flow regenerative (PR) lime kiln. This process combines 2 advantages. First, optimum



Figure 11.17-1. Process flow diagram for lime manufacturing.⁴ (SCC = Source Classification Code.)

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heating conditions for lime calcining are achieved by concurrent flow of the charge material and combustion gases. Second, the multiple-chamber regenerative process uses the charge material as the heat transfer medium to preheat the combustion air. The basic PR system has 2 shafts, but 3 shaft systems are used with small size grains to address the increased flow resistance associated with smaller feed sizes.

In the 2-shaft system, the shafts alternate functions, with 1 shaft serving as the heating shaft and the other as the flue gas shaft. Limestone is charged alternatively to the 2 shafts and flows downward by gravity flow. Each shaft includes a heating zone, a combustion/burning zone, and a cooling zone. The 2 shafts are connected in the middle to allow gas flow between them. In the heating shaft, combustion air flows downward through the heated charge material. After being preheated by the charge material, the combustion air combines with the fuel (natural gas or oil), and the air/fuel mixture is fired downward into the combustion zone. The hot combustion gases pass from the combustion zone in the heating shaft to the combustion zone in the flue gas shaft. The heated exhaust gases flow upward through the flue gas shaft combustion zone and into the preheating zone where they heat the charge material. The function of the 2 shafts reverses on a 12-minute cycle. The bottom of both shafts is a cooling zone. Cooling air flows upward through the shaft countercurrently to the flow of the calcined product. This air mixes with the combustion gases in the crossover area providing additional combustion air. The product flows by gravity from the bottom of both shafts.

About 15 percent of all lime produced is converted to hydrated (slaked) lime. There are 2 kinds of hydrators: atmospheric and pressure. Atmospheric hydrators, the more prevalent type, are used in continuous mode to produce high-calcium and dolomitic hydrates. Pressure hydrators, on the other hand, produce only a completely hydrated dolomitic lime and operate only in batch mode. Generally, water sprays or wet scrubbers perform the hydrating process and prevent product loss. Following hydration, the product may be milled and then conveyed to air separators for further drying and removal of coarse fractions.

The major uses of lime are metallurgical (aluminum, steel, copper, silver, and gold industries), environmental (flue gas desulfurization, water softening, pH control, sewage-sludge destabilization, and hazardous waste treatment), and construction (soil stabilization, asphalt additive, and masonry lime).

11.17.2 Emissions And Controls^{1-4,33}

Potential air pollutant emission points in lime manufacturing plants are indicated by SCC in Figure 11.17-1. Except for gaseous pollutants emitted from kilns, particulate matter (PM) is the only dominant pollutant. Emissions of filterable PM from rotary lime kilns constructed or modified after May 3, 1977 are regulated to 0.30 kilograms per megagram (kg/Mg) (0.60 pounds per ton [lb/ton]) of stone feed under 40 CFR Part 60, subpart HH.

The largest ducted source of particulate is the kiln. The properties of the limestone feed and the ash content of the coal (in coal-fired kilns) can significantly affect PM emission rates. Of the various kiln types, fluidized beds have the highest levels of uncontrolled PM emissions because of the very small feed rate combined with the high air flow through these kilns. Fluidized bed kilns are well controlled for maximum product recovery. The rotary kiln is second worst in uncontrolled PM emissions because of the small feed rate and relatively high air velocities and because of dust entrainment caused by the rotating chamber. The calcimatic (rotary hearth) kiln ranks third in dust production primarily because of the larger feed rate and the fact that, during calcination, the limestone remains stationary relative to the hearth. The vertical kiln has the lowest uncontrolled dust emissions

due to the large lump feed, the relatively low air velocities, and the slow movement of material through the kiln. In coal-fired kilns, the properties of the limestone feed and the ash content of the coal can significantly affect PM emissions.

Some sort of particulate control is generally applied to most kilns. Rudimentary fallout chambers and cyclone separators are commonly used to control the larger particles. Fabric and gravel bed filters, wet (commonly venturi) scrubbers, and electrostatic precipitators are used for secondary control.

Carbon monoxide (CO), carbon dioxide (CO₂), sulfur dioxide (SO₂), and nitrogen oxides (NO_x) are all produced in kilns. Sulfur dioxide emissions are influenced by several factors, including the sulfur content of the fuel, the sulfur content and mineralogical form (pyrite or gypsum) of the stone feed, the quality of lime being produced, and the type of kiln. Due to variations in these factors, plant-specific SO₂ emission factors are likely to vary significantly from the average emission factors presented here. The dominant source of sulfur emissions is the kiln's fuel, and the vast majority of the fuel sulfur is not emitted because of reactions with calcium oxides in the kiln. Sulfur dioxide emissions may be further reduced if the pollution equipment uses a wet process or if it brings CaO and SO₂ into intimate contact.

Product coolers are emission sources only when some of their exhaust gases are not recycled through the kiln for use as combustion air. The trend is away from the venting of product cooler exhaust, however, to maximize fuel use efficiencies. Cyclones, baghouses, and wet scrubbers have been used on coolers for particulate control.

Hydrator emissions are low because water sprays or wet scrubbers are usually installed to prevent product loss in the exhaust gases. Emissions from pressure hydrators may be higher than from the more common atmospheric hydrators because the exhaust gases are released intermittently, making control more difficult.

Other particulate sources in lime plants include primary and secondary crushers, mills, screens, mechanical and pneumatic transfer operations, storage piles, and roads. If quarrying is a part of the lime plant operation, particulate emissions may also result from drilling and blasting. Emission factors for some of these operations are presented in Sections 11.19 and 13.2 of this document.

Tables 11.17-1 (metric units) and 11.17-2 (English units) present emission factors for PM emissions from lime manufacturing calcining, cooling, and hydrating. Tables 11.17-3 (metric units) and 11.17-4 (English units) include emission factors for the mechanical processing (crushing, screening, and grinding) of limestone and for some materials handling operations. Section 11.19, Construction Aggregate Processing, also includes stone processing emission factors that are based on more recent testing, and, therefore, may be more representative of emissions from stone crushing, grinding, and screening. In addition, Section 13.2, Fugitive Dust Sources, includes emission factors for materials handling that may be more representative of materials handling emissions than the emission factors in Tables 11.17-3 and 11.17-4.

Emission factors for emissions of SO₂, NO_x, CO, and CO₂ from lime manufacturing are presented in Tables 11.17-5 and 11.17-6. Particle size distribution for rotary lime kilns is provided in Table 11.17-7.

EMISSION FACTORS

Table 11.17-1 (Metric Units). EMISSION FACTORS FOR LIME MANUFACTURING CALCINING, COOLING, AND HYDRATING^a

	Filterable ^b			Condensable PM ^c				
Source	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Coal-fired rotary kiln (SCC 3-05-016-18)	180 ^d	D	22 ^e	D	0.67 ^f	D	0.51 ^g	E
Coal-fired rotary kiln with large diameter cyclone (SCC 3-05-016-18)	60 ^h	D	ND		ND		ND	
Coal-fired rotary kiln with fabric filter (SCC 3-05-016-18)	0.14 ^j	D	0.077 ^k	D	0.19 ^m	E	ND	
Coal-fired rotary kiln with ESP (SCC 3-05-016-18)	4.3 ^h	D	2.2 ⁿ	D	ND		ND	
Coal-fired rotary kiln with venturi scrubber (SCC 3-05-016-18)	0.72 ^p	D	ND		0.14 ^q	D	ND	
Gas-fired rotary kiln with ESP (SCC 3-05-016-19)	0.086 ^r	E	ND		0.11 ^r	E	ND	
Gas-fired rotary kiln with gravel bed filter (SCC 3-05-016-19)	0.51 ^s	Ε	ND		0.24 ⁸	Е	ND	
Coal- and gas fired rotary kiln (SCC 3-05-016-20)	40 ^t	Е	ND	:	ND		ND	
Coal- and gas-fired rotary kiln with venturi scrubber (SCC 3-05-016-20)	0.44 ^t	D	ND		0.041 ^t	D	ND	
Coal- and coke-fired rotary kiln with venturi scrubber (SCC 3-05-016-21)	0.83 ^u	D	ND		ND		ND	
Coal-fired rotary preheater kiln with multiclone (SCC 3-05-016-22)	42 ^v	E	ND		0.040 ^v	E	ND	
Coal-fired rotary preheater kiln with gravel bed filter (SCC 3-05-016-22)	0.59 [₩]	E	ND		ND		ND	
Coal-fired rotary preheater kiln with multiclone, water spray, and fabric filter (SCC 3-05-016-22)	0.56 ^x	E	ND		0.57 ^x	E	0.076 ^x	Е

Table	2 11. 1	17-1	(cont.)	
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	Filterable ^b				Condensable PM ^c			
Source	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Gas-fired calcimatic kiln (SCC 3-05-016-05)	48 ^y	Е	ND		0.14 ^y	Е	ND	
Gas-fired parallel flow regenerative kiln with fabric filter (SCC 3-05-016-23)	0.051 ^z	D	ND		ND		ND	
Atmospheric hydrator with wet scrubber (SCC 3-05-016-09)	0.033 ^{aa}	D	ND		0.0067 ⁸⁸	D	ND	
Product cooler (SCC 3-05-016-11)	3.4 ^y	E	ND	i	0.011 ^y	Е	ND	

^a Factors represent uncontrolled emissions unless otherwise noted. All emission factors in kg/Mg of lime produced unless noted. ND = no data. SCC = Source Classification Code.
 ^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.
 ^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d References 9-10. ^e References 4,9-10. ^f References 9,11.

- ^g Reference 9.
- ^h Reference 10.
- ^j References 10,18,29,31.
- ^k References 4,10,18,29,31.
- ^mReferences 7,18-21,31.
- ⁿ References 4,10.
- ^p References 8,26-27.
- ^q References 8,13-14.
- ^r Reference 12.
- ^s References 15,30.
- ^t Reference 17.
- ^u Reference 28.
- ^v Reference 11.
- ^wReference 16.
- ^x Reference 32.
- ^y Reference 23.
- ^z Reference 34.
- ^{aa}Reference 22; units are kg/Mg of hydrated lime produced.

Table 11.17-2 (English Units). EMISSION FACTORS FOR LIME MANUFACTURING CALCINING, COOLING, AND HYDRATING^a

	Filterable ^b			Condensable PM ^c				
Source	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Coal-fired rotary kiln (SCC 3-05-016-18)	350 ^d	D	42°	D	1.3 ^f	D	1.0 ^g	Е
Coal-fired rotary kiln with large diameter cyclone (SCC 3-05-016-18)	120 ^h	D	ND		ND		ND	
Coal-fired rotary kiln with fabric filter (SCC 3-05-016-18)	0.28 ^j	D	0.15 ^k	D	0.38 ^m	Е	ND	
Coal-fired rotary kiln with ESP (SCC 3-05-016-18)	8.5 ^h	D	4.3 ⁿ	D	ND		ND	
Coal-fired rotary kiln with venturi scrubber (SCC 3-05-016-18)	1.4 ^p	D	ND		0.28 ^q	D	ND	
Gas-fired rotary kiln with ESP (SCC 3-05-016-19)	0.17 ^r	E	ND	-	0.22 ^r	Е	ND	
Gas-fired rotary kiln with gravel bed filter (SCC 3-05-016-19)	0.99 ⁸	Е	ND		0.48 ^s	Е	ND	
Coal- and gas fired rotary kiln (SCC 3-05-016-20)	80 ^t	Е	ND		ND		ND	
Coal- and gas-fired rotary kiln with venturi scrubber (SCC 3-05-016-20)	0.87 ^t	D	ND		0.082 ^t	D	ND	:
Coal- and coke-fired rotary kiln with venturi scrubber (SCC 3-05-016-21)	1.7 ^u	D	ND		ND		ND	
Coal-fired rotary preheater kiln with multiclone (SCC 3-05-016-22)	84 ^v	Е	ND		0.081 ^v	Е	ND	
Coal-fired rotary preheater kiln with gravel bed filter (SCC 3-05-016-22)	1.2 ^w	E	ND		ND		ND	
Coal-fired rotary preheater kiln with multiclone, water spray, and fabric filter (SCC 3-05-016-22)	1.1 ^x	E	ND		1.1 [×]	E	0.15 ^x	E
Gas-fired calcimatic kiln (SCC 3-05-016-05)	97 ^y	Е	ND		0.27 ^y	Е	ND	

	Filterable ^b				Condensable PM ^c			
Source	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Gas-fired parallel flow regenerative kiln with fabric filter (SCC 3-05-016-23)	0.026 ^z	D	ND		ND		ND	
Atmospheric hydrator with wet scrubber (SCC 3-05-016-09)	0.067 ⁸⁸	D	ND		0.013 ^{aa}	D	ND	
Product cooler (SCC 3-05-016-11)	6.8 ^y	Е	ND		0.023 ^y	E	ND	

^a Factors represent uncontrolled emissions unless otherwise noted. Factors are lb/ton of lime produced unless noted. ND = no data. SCC = Source Classification Code.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. ^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d References 9-10.

^c References 4,9-10.

References 9,11.

- ^g Reference 9.
- ^h Reference 10.
- ^j References 10,18,29,31. ^k References 4,10,18,29,31. ^m References 7,18-21,31.
- ⁿ References 4,10.
- ^p References 8,26-27.
- ^q References 8,13-14.
- ^r Reference 12.
- ^s References 15,30.
- ^t Reference 17.
- ^u Reference 28.
- ^v Reference 11.
- ^w Reference 16.
- ^x Reference 32.
- ^y Reference 23.
- ^z Reference 34.
- ^{aa} Reference 22; units are lb/ton of hydrated lime produced.

EMISSION FACTORS

Table 11.17-3 (Metric Units).EMISSION FACTORS FOR LIME MANUFACTURING
RAW MATERIAL AND PRODUCT PROCESSING AND HANDLING^a

	Filterable ^b						
Source	РМ	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING			
Primary crusher ^c (SCC 3-05-016-01)	0.0083	E	ND				
Scalping screen and hammermill (secondary crusher) ^c (SCC 3-05-016-02)	0.31	E	ND				
Primary crusher with fabric filter ^d (SCC 3-05-016-01)	0.00021	D	ND				
Primary screen with fabric filter ^e (SCC 3-05-016-16)	0.0030	D	ND				
Crushed material conveyor transfer with fabric filter ^f (SCC 3-05-016-24)	4.4x10 ⁻⁵	D	ND				
Secondary and tertiary screen with fabric filter ^g (SCC 3-05-016-25)	6.5x10 ⁻⁵	D	ND				
Product transfer and conveying (SCC 3-05-016-15) ^h	1.1	Е	ND				
Product loading, enclosed truck (SCC 3-05-016-26) ^h	0.31	D	ND				
Product loading, open truck (SCC 3-05-016-27) ^h	0.75	D	ND				

^a Factors represent uncontrolled emissions unless otherwise noted. Factors are kg/Mg of material processed unless noted. ND = no data. SCC = Source Classification Code.

- ^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.
- ^c Reference 6; units of kg/Mg of stone processed.
- ^d Reference 34. Emission factors in units of kg/Mg of material processed. Includes scalping screen, scalping screen discharges, primary crusher, primary crusher discharges, and ore discharge.
- ^e Reference 34. Emission factors in units of kg/Mg of material processed. Includes primary screening, including the screen feed, screen discharge, and surge bin discharge.
- ^f Reference 34. Emission factors in units of kg/Mg of material processed. Based on average of three runs each of emissions from two conveyor transfer points on the conveyor from the primary crusher to the primary stockpile.
- ^g Reference 34. Emission factors in units of kg/Mg of material processed. Based on sum of emissions from two emission points that include conveyor transfer point for the primary stockpile underflow to the secondary screen, secondary screen, tertiary screen, and tertiary screen discharge.
- ^h Reference 10; units of kg/Mg of product loaded.
| | | Filterab | le ^b | |
|---|----------------------|------------------------------|-----------------|------------------------------|
| Source | РМ | EMISSION
FACTOR
RATING | PM-10 | EMISSION
FACTOR
RATING |
| Primary crusher ^c
(SCC 3-05-016-01) | 0.017 | E | ND | |
| Scalping screen and hammermill (secondary crusher)
(SCC 3-05-016-02) ^c | 0.62 | Е | ND | |
| Primary crusher with fabric filter ^d
(SCC 3-05-016-01) | 0.00043 | D | ND | |
| Primary screen with fabric filter ^e
(SCC 3-05-016-16) | 0.00061 | D | ND | |
| Crushed material conveyor transfer with fabric filter ^f
(SCC 3-05-016-24) | 8.8x10 ⁻⁵ | D | ND | |
| Secondary and tertiary screen with fabric filter ^g
(SCC 3-05-016-25) | 0.00013 | D | ND | |
| Product transfer and conveying
(SCC 3-05-016-15) ^h | 2.2 | Е | ND | |
| Product loading, enclosed truck
(SCC 3-05-016-26) ^h | 0.61 | D | ND | |
| Product loading, open truck
(SCC 3-05-016-27) ^h | 1.5 | D | ND | |

Table 11.17-4 (English Units).EMISSION FACTORS FOR LIME MANUFACTURING
RAW MATERIAL AND PRODUCT PROCESSING AND HANDLING^a

^a Factors represent uncontrolled emissions unless otherwise noted. Factors are lb/ton of material processed unless noted. ND = no data. SCC = Source Classification Code.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Reference 6; factors are lb/ton.

^d Reference 34. Factors are lb/ton of material processed. Includes scalping screen, scalping screen discharges, primary crusher, primary crusher discharges, and ore discharge.

- ^e Reference 34. Factors are lb/ton of material processed. Includes primary screening, including the screen feed, screen discharge, and surge bin discharge.
- ^f Reference 34. Factors are lb/ton of material processed. Based on average of three runs each of emissions from two conveyor transfer points on the conveyor from the primary crusher to the primary stockpile.
- ^g Reference 34. Emission factors in units of kg/Mg of material processed. Based on sum of emissions from two emission points that include conveyor transfer point for the primary stockpile underflow to the secondary screen, secondary screen, tertiary screen, and tertiary screen discharge.

^h Reference 10; units are lb/ton of product loaded.

Table 11.17-5 (Metric Units). EMISSION FACTORS FOR LIME MANUFACTURING^a

		EMISSION FACTOR		EMISSION FACTOR		EMISSION FACTOR		EMISSION FACTOR		EMISSION FACTOR
Source	SO2 ^b	RATING	SO3	RATING	NOx	RATING	CO	RATING	CO ₂ ^c	RATING
Coal-fired rotary kiln (SCC 3-05-016-18)	2.7 ^d	D	ND		1.6 ^e	С	0.74 ^f	D	1,600 ^g	С
Coal-fired rotary kiln with fabric filter (SCC 3-05-016-18)	0.83 ^h	D	ND		ND		ND		ND	
Coal-fired rotary kiln with wet scrubber (SCC 3-05-016-18)	0.15 ^j	D	0.11 ^k	E	ND		ND		ND	
Gas-fired rotary kiln (SCC 3-05-016-19)	ND		ND		1.7 ^m	Е	1.1 ^m	Ε	ND	
Coal- and gas-fired rotary kiln with venturi scrubber (SCC 3-05-016-20)	ND		ND		1.4 ⁿ	D	0.41 ⁿ	D	1 ,600ⁿ	D
Coal- and coke-fired rotary kiln with venturi scrubber (SCC 3-05-016-21)	ND		ND		ND		ND		1, 500 p	D
Coal-fired rotary preheater kiln with dry PM controls (SCC 3-05-016-22)	1.1 ^q	E	ND		ND		ND		ND	
Coal-fired rotary preheater kiln with multiclone, water spray, and fabric filter (SCC 3-05-016-22)	3.2 ^r	E	ND		ND		3.2 ^r	E	1,200 ^r	E
Gas-fired calcimatic kiln (SCC 3-05-016-05)	ND	-	ND		0.076 ^s	D	ND	_	1,300	E
Gas-fired parallel flow regenerative kiln with fabric filter (SCC 3-05-016-23)	0.0060 ^t	D	ND		0.12 ^t	D	0.23 ^t	D	ND	
Product cooler (SCC 3-05-016-11)	ND	ND			ND		ND		3.9 ⁸	E

^a Factors represent uncontrolled emissions unless otherwise noted. Factors are kg/Mg of lime produced unless noted. ND = no data. SCC = Source Classification Code.
 ^b Mass balance on sulfur may yield a more representative emission factor for a specific facility.
 ^c Mass balance on carbon may yield a more representative emission factor for a specific facility.

^d References 9,18.

e References 9,11,18,29,31. f References 18,25.

^g References 8-9,24-27,29.

Table 11.17-5 (cont.).

h References 18,29,31.
j Reference 25.
k Reference 13.
^m Reference 12.
n Reference 17.
P Reference 28.
q Reference 32.
^q Reference 32.
^s Reference 23.
t Reference 34.

Table 11.17-6 (English Units). EMISSION FACTORS FOR LIME MANUFACTURING^a

Source	so ₂ b	EMISSION FACTOR RATING	SO3	EMISSION FACTOR RATING	NO _x	EMISSION FACTOR RATING	со	EMISSION FACTOR RATING	co ₂ °	EMISSION FACTOR RATING
Coal-fired rotary kiln (SCC 3-05-016-18)	5.4 ^d	D	ND		3.1 ^e	С	1.5 ^f	D	3,200 ^g	С
Coal-fired rotary kiln with fabric filter (SCC 3-05-016-18)	1.7 ^h	D	ND		ND		ND		ND	
Coal-fired rotary kiln with wet scrubber (SCC 3-05-016-18)	0 30 ^j	D	0.21 ^k	E	ND		ND		ND	
Gas-fired rotary kiln (SCC 3-05-016-19)	ND		ND		3.5 ^m	E	2.2 ^m	Ε	ND	
Coal- and gas fired rotary kiln with venturi scrubber (SCC 3-05-016-20)	ND		ND		2.7 ⁿ	D	0.83 ⁿ	D	3,200 ⁿ	D
Coal- and coke-fired rotary kiln with venturi scrubber (SCC 3-05-016-21)	ND		ND		ND		ND		3,000 ^p	D
Coal-fired rotary preheater kiln with dry PM controls (SCC 3-05-016-22)	2.3 ^q	Е	ND		ND		ND		ND	
Coal-fired rotary preheater kiln with multiclone, water spray, and fabric filter (SCC 3-05-016-22)	6.4 ^r	F	ND		ND		6.3 ^r	E	2,400 ^r	E
Gas-fired calcimatic kiln (SCC 3-05-016-05)	ND		ND		0.15 ^s	D	ND		2,700 ^s	Е
Gas-fired parallel flow regenerative kiin with fabric filter (SCC 3-05-016-23)	0.0012 ^t	D	ND		0.24 ^t	D	0.45 ^t	D	ND	
Product cooler (SCC 3-05-016-11)	ND		ND		ND		ND		7.8 ^s	E

^a Factors represent uncontrolled emissions unless otherwise noted. Factors are lb/ton of lime produced unless noted. ND = no data. SCC = Source Classification Code.
^b Mass balance on sulfur may yield a more representative emission factor for a specific facility.
^c Mass balance on carbon may yield a more representative emission factor for a specific facility.
^d References 9,18.
^e References 9,11,18,29,31.
^f References 18,25.
^g References 8-9,24-27,29.

Mineral Products Industry

Table 11.17-6 (cont.).

- ^h References 18,29,31.
 ^j Reference 25.
- k Reference 13. ^m Reference 12.
- ⁿ Reference 17.
- ^p Reference 28.
- ^q References 16,24.
- ^r Reference 32.
- ^s Reference 23.
- ^t Reference 34.

Table 11.17-7. AVERAGE PARTICLE SIZE DISTRIBUTION FOR ROTARY LIME KILNS^a

	Cumulative Mass Percent Less Than Stated Particle Size									
Particle Size (µm)	Uncontrolled Rotary Kiln	Rotary Kiln With Multiclone	Rotary Kiln With ESP	Rotary Kiln With Fabric Filter						
2.5	1.4	6.1	14	27						
5.0	2.9	9.8	ND	ND						
10.0	12	16	50	55						
15.0	31	23	62	73						
20.0	ND	31	ND	ND						

^a Reference 4, Table 4-28; based on A- and C-rated particle size data. Source Classification Codes 3-05-016-04, and -18 to -21. ND = no data.

Because of differences in the sulfur content of the raw material and fuel and in process operations, a mass balance on sulfur may yield a more representative emission factor for a specific facility than the SO₂ emission factors presented in Tables 11.17-5 and 11.17-6. In addition, CO₂ emission factors estimated using a mass balance on carbon may be more representative for a specific facility than the CO₂ emission factors presented in Tables 11.17-5 and 11.17-6. Additional information on estimating emission factors for CO₂ emissions from lime kilns can be found in the background report for this AP-42 section.

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11.18 Mineral Wool Manufacturing

11.18.1 General 1,2

Mineral wool often is defined as any fibrous glassy substance made from minerals (typically natural rock materials such as basalt or diabase) or mineral products such as slag and glass. Because glass wool production is covered separately in AP-42 (Section 11.13), this section deals only with the production of mineral wool from natural rock and slags such as iron blast furnace slag, the primary material, and copper, lead, and phosphate slags. These materials are processed into insulation and other fibrous building materials that are used for structural strength and fire resistance. Generally, these products take 1 of 4 forms: "blowing" wool or "pouring" wool, which is put into the structural spaces of buildings; batts, which may be covered with a vapor barrier of paper or foil and are shaped to fit between the structural members of buildings; industrial and commercial products such as high-density fiber felts and blankets, which are used for insulating boilers, ovens, pipes, refrigerators, and other process equipment; and bulk fiber, which is used as a raw material in manufacturing other products, such as ceiling tile, wall board, spray-on insulation, cement, and mortar.

Mineral wool manufacturing facilities are included in Standard Industrial Classification (SIC) Code 3296, mineral wool. This SIC code also includes the production of glass wool insulation products, but those facilities engaged in manufacturing textile glass fibers are included in SIC Code 3229. The 6-digit Source Classification Code (SCC) for mineral wool manufacturing is 3-05-017.

11.18.2 Process Description^{1,4,5}

Most mineral wool produced in the United States today is produced from slag or a mixture of slag and rock. Most of the slag used by the industry is generated by integrated iron and steel plants as a blast furnace byproduct from pig iron production. Other sources of slag include the copper, lead, and phosphate industries. The production process has 3 primary components--molten mineral generation in the cupola, fiber formation and collection, and final product formation. Figure 11.18-1 illustrates the mineral wool manufacturing process.

The first step in the process involves melting the mineral feed. The raw material (slag and rock) is loaded into a cupola in alternating layers with coke at weight ratios of about 5 to 6 parts mineral to 1 part coke. As the coke is ignited and burned, the mineral charge is heated to the molten state at a temperature of 1300 to 1650°C (2400 to 3000°F). Combustion air is supplied through tuyeres located near the bottom of the furnace. Process modifications at some plants include air enrichment and the use of natural gas auxiliary burners to reduce coke consumption. One facility also reported using an aluminum flux byproduct to reduce coke consumption.

The molten mineral charge exits the bottom of the cupola in a water-cooled trough and falls onto a fiberization device. Most of the mineral wool produced in the United States is made by variations of 2 fiberization methods. The Powell process uses groups of rotors revolving at a high rate of speed to form the fibers. Molten material is distributed in a thin film on the surfaces of the rotors and then is thrown off by centrifugal force. As the material is discharged from the rotor, small globules develop on the rotors and form long, fibrous tails as they travel horizontally. Air or steam may be blown around the rotors to assist in fiberizing the material. A second fiberization method, the Downey process, uses a spinning concave rotor with air or steam attenuation. Molten material is



Figure 11.18-1. Mineral wool manufacturing process flow diagram. (Source Classification Codes in parentheses.)

distributed over the surface of the rotor, from which it flows up and over the edge and is captured and directed by a high-velocity stream of air or steam.

During the spinning process, not all globules that develop are converted into fiber. The nonfiberized globules that remain are referred to as "shot." In raw mineral wool, as much as half of the mass of the product may consist of shot. As shown in Figure 11.18-1, shot is usually separated from the wool by gravity immediately following fiberization.

Depending on the desired product, various chemical agents may be applied to the newly formed fiber immediately following the rotor. In almost all cases, an oil is applied to suppress dust and, to some degree, anneal the fiber. This oil can be either a proprietary product or a mediumweight fuel or lubricating oil. If the fiber is intended for use as loose wool or bulk products, no further chemical treatment is necessary. If the mineral wool product is required to have structural rigidity, as in batts and industrial felt, a binding agent is applied with or in place of the oil treatment. This binder is typically a phenol-formaldehyde resin that requires curing at elevated temperatures. Both the oil and the binder are applied by atomizing the liquids and spraying the agents to coat the airborne fiber. After formation and chemical treatment, the fiber is collected in a blowchamber. Resinand/or oil-coated fibers are drawn down on a wire mesh conveyor by fans located beneath the collector. The speed of the conveyor is set so that a wool blanket of desired thickness can be obtained.

Mineral wool containing the binding agent is carried by conveyor to a curing oven, where the wool blanket is compressed to the appropriate density and the binder is baked. Hot air, at a temperature of 150 to 320° C (300 to 600° F), is forced through the blanket until the binder has set. Curing time and temperature depend on the type of binder used and the mass rate through the oven. A cooling section follows the oven, where blowers force air at ambient temperatures through the wool blanket.

To make batts and industrial felt products, the cooled wool blanket is cut longitudinally and transversely to the desired size. Some insulation products are then covered with a vapor barrier of aluminum foil or asphalt-coated kraft paper on one side and untreated paper on the other side. The cutters, vapor barrier applicators, and conveyors are sometimes referred to collectively as a batt machine. Those products that do not require a vapor barrier, such as industrial felt and some residential insulation batts, can be packed for shipment immediately after cutting.

Loose wool products consist primarily of blowing wool and bulk fiber. For these products, no binding agent is applied, and the curing oven is eliminated. For granulated wool products, the fiber blanket leaving the blowchamber is fed to a shredder and pelletizer. The pelletizer forms small, 1-inch diameter pellets and separates shot from the wool. A bagging operation completes the processes. For other loose wool products, fiber can be transported directly from the blowchamber to a baler or bagger for packaging.

11.18.3 Emissions And Controls^{1,13}

The sources of emissions in the mineral wool manufacturing industry are the cupola; binder storage, mixing, and application; the blow chamber; the curing oven; the mineral wool cooler; materials handling and bagging operations; and waste water treatment and storage. With the exception of lead, the industry emits the full range of criteria pollutants. Also, depending on the particular types of slag and binding agents used, the facilities may emit both metallic and organic hazardous air pollutants (HAPs).

The primary source of emissions in the mineral wool manufacturing process is the cupola. It is a significant source of particulate matter (PM) emissions and is likely to be a source of PM less than 10 micrometers (μ m) in diameter (PM-10) emissions, although no particle size data are available. The cupola is also a potential source of HAP metal emissions attributable to the coke and slags used in the furnace. Coke combustion in the furnace produces carbon monoxide (CO), carbon dioxide (CO₂), and nitrogen oxide (NO_x) emissions. Finally, because blast furnace slags contain sulfur, the cupola is also a source of sulfur dioxide (SO₂) and hydrogen sulfide (H₂S) emissions.

The blowchamber is a source of PM (and probably PM-10) emissions. Also, the annealing oils and binders used in the process can lead to VOC emissions from the process. Other sources of VOC emissions include batt application, the curing oven, and waste water storage and treatment. Finally, fugitive PM emissions can be generated during cooling, handling, and bagging operations. Tables 11.18-1 and 11.18-2 present emission factors for filterable PM emissions from various mineral wool manufacturing processes; Tables 11-18.3 and 11.18-4 show emission factors for CO, CO₂, SO₂, and sulfates; and Tables 11.18-5 and 11.18-6 present emission factors for NO_x, N₂O, H₂S and fluorides.

Mineral wool manufacturers use a variety of air pollution control techniques, but most are directed toward PM control with minimal control of other pollutants. The industry has given greatest attention to cupola PM control, with two-thirds of the cupolas in operation having fabric filter control systems. Some cupola exhausts are controlled by wet scrubbers and electrostatic precipitators (ESPs); cyclones are also used for cupola PM control either alone or in combination with other control devices. About half of the blow chambers in the industry also have some level of PM control, with the predominant control device being low-energy wet scrubbers. Cyclones and fabric filters have been used to a limited degree on blow chambers. Finally, afterburners have been used to control VOC emissions from blow chambers and curing ovens and CO emissions from cupolas.

Filterab	ole PM ^b	
kg/Mg Of Product	EMISSION FACTOR RATING	
8.2	E	
0.051	D	
2.4	Ε	
1.8	Ε	
0.36	D	
6.0	Ε	
	Filterat kg/Mg Of Product 8.2 0.051 2.4 1.8 0.36 6.0	Filterable PMbkg/Mg Of ProductEMISSION FACTOR RATING8.2E0.051D2.4E1.8E0.36D6.0E

Table 11.18-1 (Metric Units). EMISSION FACTORS FOR MINERAL WOOL MANUFACTURING^a

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code.

0.45

1.2

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

^c References 1,12. Activity level is assumed to be total feed charged.

^d References 6,7,8,10,11. Activity level is total feed charged.

Blow chamber with wire mesh filter^g (SCC 3-05-017-03)

^e Reference 12.

Cooler^e (SCC 3-05-017-05)

^f Reference 9.

^g Reference 7. Activity level is mass of molten mineral feed charged.

D

E

Table 11.18-2 (English Units). EMISSION FACTORS FOR MINERAL WOOL MANUFACTURING^a

	Filterab	le PM ^b
Process	lb/ton Of Product	EMISSION FACTOR RATING
Cupola ^c (SCC 3-05-017-01)	16	E
Cupola with fabric filter ^d (SCC 3-05-017-01)	0.10	D
Reverberatory furnace ^e (SCC 3-05-017-02)	4.8	Ε
Batt curing oven ^e (SCC 3-05-017-04)	3.6	Ε
Batt curing oven with ESP ^f (SCC 3-05-017-04)	0.72	D
Blow chamber ^c (SCC 3-05-017-03)	12	E
Blow chamber with wire mesh filter ^g (SCC 3-05-017-03)	0.91	D
Cooler ^e (SCC 3-05-017-05)	2.4	Е

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source ClassificationCode.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

^c Reference 1,12. Activity level is assumed to be total feed charged. ^d References 6,7,8,10,11. Activity level is total feed charged.

^e Reference 12.

^f Reference 9.

^g Reference 7. Activity level is mass of molten mineral feed charged.

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	СОр		(CO2 ^b	S	80 ₂	SO3		
Source	kg/Mg Of Total Feed Charged	EMISSION FACTOR RATING							
Cupola (SCC 3-05-017 01)	125	D	260	D	4.0 ^c	D	3.2 ^d	Е	
Cupola with fabric filter (SCC 3-05-017-01)	NA		NA		NA		0.077 ^b	E	
Batt curing oven (SCC 3-05-017-04)	ND		ND		0.58 ^d	E	ND		
Blow chamber (SCC 3-05-017-03)	ND		80 ^e	E	0.43 ^d	Ε	ND		
Cooler (SCC 3-05-017-05)	ND		ND		0.034 ^d	E	ND	:	

Table 11.18-3 (Metric Units). EMISSION FACTORS FOR MINERAL WOOL **MANUFACTURING^a**

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. NA = not applicable. ND = no data.
^b Reference 6.
^c References 6,10,11.
^d Reference 12.

^e Reference 9.

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Table 11.18-4 (English Units). EMISSION FACTORS FOR MINERAL WOOL MANUFACTURING^a

	СОр		C	:0 ₂ ^b	s	02		so ₃
Source	lb/ton Of Total Feed Charged	EMISSION FACTOR RATING						
Cupola (SCC 3-05-017-01)	250	D	520	D	8.0 ^a	D	6.3 ^d	Е
Cupola with fabric filter (SCC 3-05-017-01)	NA		NA		NA		0.15 ^b	E
Batt curing oven (SCC 3-05-017-04)	ND		ND		1.2 ^d	Е	ND	
Blow chamber (SCC 3-05-017-03)	ND		160 ^e	Ε	0.087 ^d	Ε	ND	
Cooler (SCC 3-05-017-05)	ND		ND		0.068 ^d	E	ND	

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. NA = not applicable. ND = no data.

^b Reference 6.

^c References 6,10,11. ^d Reference 12.

^e Reference 9.

Table 11.18-5 (Metric Units).	EMISSION FACTORS FOR	MINERAL WOOL	MANUFACTURING ^a
			number of the start of the star

	NO _x		N ₂ O		Н	2 ² S	Fluorides	
Process	kg/Mg Of Total Feed Charged	EMISSION FACTOR RATING						
Cupola (SCC 3-05-017-01)	0.8 ^b	E	ND		1.5 ^b	Е	ND	
Cupola with fabric filter (SCC 3-05-017-01)	ND		ND		ND		0.019 ^c	D
Cupola with fabric filter (SCC 3-05-017-01)	ND		ND		ND		0.19 ^d	D
Batt curing oven (SCC 3-05-017-14)	ND		0.079	Е	ND		ND	

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data.
 ^b Reference 1.
 ^c References 10-11. Coke only used as fuel.
 ^d References 10-11. Fuel combination of coke and aluminum smelting byproducts.

	NO _x		N	l ₂ O		H ₂ S	Fluorides	
Process	lb/ton Of Total Feed Charged	EMISSION FACTOR RATING						
Cupola (SCC 3-05-017-01)	1.6 ^b	Е	ND		3.0 ^b	E	ND	
Cupola with fabric filter (SCC 3-05-017-01)	ND		ND		ND		0.038°	D
Cupola with fabric filter (SCC 3-05-017-01)	ND		ND		ND		0.38 ^d	D
Batt curing oven (SCC 3-05-017-14)	ND		0.16	Ε	ND		ND	

(SCC 3-05-017-14)
 ^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data.
 ^b Reference 1.
 ^c References 10-11. Coke only used as fuel.
 ^d References 10-11. Fuel combination of coke and aluminum smelting byproducts.

Mineral Products Industry

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- 2. The Facts On Rocks And Slag Wool, Pub. No. N 020, North American Insulation Manufacturers Association, Alexandria, VA, Undated.
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- 4. Personal communication between F. May, U.S.G. Corporation, Chicago, Illinois, and R. Marinshaw, Midwest Research Institute, Cary, NC, June 5, 1992.
- 5. Memorandum from K. Schuster, N. C. Department Of Environmental Management, to M. Aldridge, American Rockwool, April 25, 1988.
- 6. Sulfur Oxide Emission Tests Conducted On The #1 And #2 Cupola Stacks In Leeds, Alabama For Rock Wool Company, November 8 & 9, 1988, Guardian Systems, Inc., Leeds, AL, Undated.
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 J. A. Danielson, ed., U. S. DHEW, PHS, National Center For Air Pollution Control, Cincinnati, OH, PHS Publication Number 999-AP-40, 1967, pp. 343-347.
- 13. Personal communication between M. Johnson, U. S. Environmental Protection Agency, Research Triangle Park, NC, and D. Bullock, Midwest Research Institute, Cary, NC, March 22, 1993.

11.19 Construction Aggregate Processing¹⁻²

The construction aggregate industry covers a range of subclassifications of the nonmetallic minerals industry (see Section 11.24, Metallic Minerals Processing, for information on that similar activity). Many operations and processes are common to both groups, including mineral extraction from the earth, loading, unloading, conveying, crushing, screening, and loadout. Other operations are restricted to specific subcategories. These include wet and dry fine milling or grinding, air classification, drying, calcining, mixing, and bagging. The latter group of operations is not generally associated with the construction aggregate industry but can be conducted on the same raw materials used to produce aggregate. Two examples are processing of limestone and sandstone. Both substances can be used as construction materials and may be processed further for other uses at the same location. Limestone is a common source of construction aggregate, but it can be further milled and classified to produce agricultural limestone. Sandstone can be processed into construction sand and also can be wet and/or dry milled, dried, and air classified into industrial sand.

The construction aggregate industry can be categorized by source, mineral type or form, wet versus dry, washed or unwashed, and end uses, to name but a few. The industry is divided in this document into Section 11.19.1, Sand And Gravel Processing, and Section 11.19.2, Crushed Stone Processing. Sections on other categories of the industry will be published when data on these processes become available.

Uncontrolled construction aggregate processing can produce nuisance problems and can have an effect upon attainment of ambient particulate standards. However, the generally large particles produced often can be controlled readily. Some of the individual operations such as wet crushing and grinding, washing, screening, and dredging take place with "high" moisture (more than about 1.5 to 4.0 weight percent). Such wet processes do not generate appreciable particulate emissions.

References For Section 11.19

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11.19.1 Sand And Gravel Processing

11.19.1.1 Process Description¹⁻⁶

Deposits of sand and gravel, the unconsolidated granular materials resulting from the natural disintegration of rock or stone, are generally found in near-surface alluvial deposits and in subterranean and subaqueous beds. Sand and gravel are siliceous and calcareous products of the weathering of rocks and unconsolidated or poorly consolidated materials. Such deposits are common throughout the country. The six-digit Source Classification Code (SCC) for construction sand and gravel processing is 3-05-025, and the six-digit SCC for industrial sand and gravel is 3-05-027.

Construction Sand And Gravel -

Sand and gravel typically are mined in a moist or wet condition by open pit excavation or by dredging. Open pit excavation is carried out with power shovels, draglines, front end loaders, and bucket wheel excavators. In rare situations, light charge blasting is done to loosen the deposit. Mining by dredging involves mounting the equipment on boats or barges and removing the sand and gravel from the bottom of the body of water by suction or bucket-type dredges. After mining, the materials are transported to the processing plant by suction pump, earth mover, barge, truck, belt conveyors, or other means.

Although significant amounts of sand and gravel are used for fill, bedding, subbase, and basecourse without processing, most domestic sand and gravel are processed prior to use. The processing of sand and gravel for a specific market involves the use of different combinations of washers, screens, and classifiers to segregate particle sizes; crushers to reduce oversized material; and storage and loading facilities. A process flow diagram for construction sand and gravel processing is presented in Figure 11.19.1-1. The following paragraphs describe the process in more detail.

After being transported to the processing plant, the wet sand and gravel raw feed is stockpiled or emptied directly into a hopper, which typically is covered with a "grizzly" of parallel bars to screen out large cobbles and boulders. From the hopper, the material is transported to fixed or vibrating scalping screens by gravity, belt conveyors, hydraulic pump, or bucket elevators. The scalping screens separate the oversize material from the smaller, marketable sizes. Oversize material may be used for erosion control, reclamation, or other uses, or it may be directed to a crusher for size reduction, to produce crushed aggregate, or to produce manufactured sands. Crushing generally is carried out in one or two stages, although three-stage crushing may also be performed. Following crushing, the material is returned to the screening operation for sizing.

The material that passes through the scalping screen is fed into a battery of sizing screens, which generally consists of either horizontal or sloped, and either single or multideck, vibrating screens. Rotating trommel screens with water sprays are also used to process and wash wet sand and gravel. Screening separates the sand and gravel into different size ranges. Water is sprayed onto the material throughout the screening process. After screening, the sized gravel is transported to stockpiles, storage bins, or, in some cases, to crushers by belt conveyors, bucket elevators, or screw conveyors.

The sand is freed from clay and organic impurities by log washers or rotary scrubbers. After scrubbing, the sand typically is sized by water classification. Wet and dry screening is rarely used to size the sand. After classification, the sand is dewatered using screws, separatory cones, or

Sand And Gravel Processing



Figure 11.19.1-1. Process flow diagram for construction sand and gravel processing. (Source Classification Codes in parentheses.)

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hydroseparators. Material may also be rodmilled to produce smaller sized fractions, although this practice is not common in the industry. After processing, the sand is transported to storage bins or stockpiles by belt conveyors, bucket elevators, or screw conveyors.

Industrial Sand And Gravel -

Industrial sand and gravel typically are mined from open pits of naturally occurring quartzrich sand and sandstone. Mining methods depend primarily on the degree of cementation of the rock. In some deposits, blasting is required to loosen the material prior to processing. The material may undergo primary crushing at the mine site before being transported to the processing plant. Figure 11.19.1-2 is a flow diagram for industrial sand and gravel processing.

The mined rock is transported to the processing site and stockpiled. The material then is crushed. Depending on the degree of cementation, several stages of crushing may be required to achieve the desired size reduction. Gyratory crushers, jaw crushers, roll crushers, and impact mills are used for primary and secondary crushing. After crushing, the size of the material is further reduced to 50 micrometers (μ m) or smaller by grinding, using smooth rolls, media mills, autogenous mills, hammer mills, or jet mills. The ground material then is classified by wet screening, dry screening, or air classification. At some plants, after initial crushing and screening, a portion of the sand may be diverted to construction sand use.

After initial crushing and screening, industrial sand and gravel are washed to remove unwanted dust and debris and are then screened and classified again. The sand (now containing 25 to 30 percent moisture) or gravel then goes to an attrition scrubbing system that removes surface stains from the material by rubbing in an agitated, high-density pulp. The scrubbed sand or gravel is diluted with water to 25 to 30 percent solids and is pumped to a set of cyclones for further desliming. If the deslimed sand or gravel contains mica, feldspar, and iron bearing minerals, it enters a froth flotation process to which sodium silicate and sulfuric acid are added. The mixture then enters a series of spiral classifiers where the impurities are floated in a froth and diverted to waste. The purified sand, which has a moisture content of 15 to 25 percent, is conveyed to drainage bins where the moisture content is reduced to about 6 percent. The material is then dried in rotary or fluidized bed dryers to a moisture content of less than 0.5 percent. The dryers generally are fired with natural gas or oil, although other fuels such as propane or diesel also may be used. After drying, the material is cooled and then undergoes final screening and classification prior to being stored and packaged for shipment.

11.19.1.2 Emissions And Controls⁶⁻¹⁴

Emissions from the production of sand and gravel consist primarily of particulate matter (PM) and particulate matter less than 10 micrometers (PM-10) in aerodynamic diameter, which are emitted by many operations at sand and gravel processing plants, such as conveying, screening, crushing, and storing operations. Generally, these materials are wet or moist when handled, and process emissions are often negligible. A substantial portion of these emissions may consist of heavy particles that settle out within the plant. Other potentially significant sources of PM and PM-10 emissions are haul roads. Emissions from dryers include PM and PM-10, as well as typical combustion products including CO, CO_2 , and NO_x . In addition, dryers may be sources of volatile organic compounds (VOC) or sulfur oxides (SO_x) emissions, depending on the type of fuel used to fire the dryer.

With the exception of drying, emissions from sand and gravel operations primarily are in the form of fugitive dust, and control techniques applicable to fugitive dust sources are appropriate. Some successful control techniques used for haul roads are dust suppressant application, paving, route



Figure 11.19.1-2. Process flow diagram for industrial sand and gravel processing. (Source Classification Codes in parentheses.)

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modifications, and soil stabilization; for conveyors, covering and wet suppression; for storage piles, wet suppression, windbreaks, enclosure, and soil stabilizers; for conveyor and batch transfer points, wet suppression and various methods to reduce freefall distances (e. g., telescopic chutes, stone ladders, and hinged boom stacker conveyors); and for screening and other size classification, covering and wet suppression.

Wet suppression techniques include application of water, chemicals and/or foam, usually at crusher or conveyor feed and/or discharge points. Such spray systems at transfer points and on material handling operations have been estimated to reduce emissions 70 to 95 percent. Spray systems can also reduce loading and wind erosion emissions from storage piles of various materials 80 to 90 percent. Control efficiencies depend upon local climatic conditions, source properties and duration of control effectiveness. Wet suppression has a carryover effect downstream of the point of application of water or other wetting agents, as long as the surface moisture content is high enough to cause the fines to adhere to the larger rock particles.

In addition to fugitive dust control techniques, some facilities use add-on control devices to reduce emissions of PM and PM-10 from sand and gravel processing operations. Controls in use include cyclones, wet scrubbers, venturi scrubbers, and fabric filters. These types of controls are rarely used at construction sand and gravel plants, but are more common at industrial sand and gravel processing facilities.

Emission factors for criteria pollutant emissions from industrial sand and gravel processing are presented in Table 11.19.1-1 (metric and English units), and emission factors for organic pollutant emissions from industrial sand and gravel processing are presented in Table 11.19.1-2 (metric and English units). Although no emission factors are presented for construction sand and gravel processing, emission factors for the crushing, screening, and handling and transfer operations associated with stone crushing can be found in Section 11.19.2, "Crushed Stone Processing." In the absence of other data, the emission factors presented in Section 11.19.2 can be used to estimate emissions from corresponding sand and gravel processing sources. The background report for this AP-42 section also presents factors for the combined emissions of total suspended particulate from construction gravel storage pile wind erosion, material handling, and vehicle traffic. However, because the applicability of those emission factors to other storage piles is questionable, they are not presented here. To estimate emissions from fugitive sources, refer to AP-42 Chapter 13, "Miscellaneous Sources". The emission factors for industrial sand storage and screening presented in Table 11.19.1-1 are not recommended as surrogates for construction sand and gravel processing, because they are based on emissions from dried sand and may result in overestimates of emissions from those sources. Construction sand and gravel are processed at much higher moisture contents.

Table 11.19.1-1 (Metric And English Units). EMISSION FACTORS FOR INDUSTRIAL SAND AND GRAVEL PROCESSING^a

	Total	РМ	N	0 _x	CO ₂	
Source	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Sand dryer (SCC 3-05-027-20)	0.98 ^{b,c}	2.0 ^{b,c}	0.016 ^d	0.031 ^d	14 ^e	27 ^e
Sand dryer with wet scrubber (SCC 3-05-027-20)	0.019 ^{b,f}	0.039 ^{b,f}	g	g	g	g
Sand dryer with fabric filter (SCC 3-05-027-20)	0.0053 ^{b,h}	0.010 ^{b,h}	g	g	g	g
Sand handling, transfer, and storage with wet scrubber (SCC 3-05-027-60)	0.00064 ^j	0.0013 ^j	ND	ND	ND	ND
Sand screening with venturi scrubber (SCC 3-05-027-13)	0.0042 ^k	0.0083 ^k	ND	ND	ND	ND

EMISSION FACTOR RATING: D

- ^a Factors represent uncontrolled emissions unless noted. Dryer emission factors in units of kg/Mg and lb/ton of dried material produced; other factors in units of kg/Mg and lb/ton of material stored or screened. SCC = Source Classification Code.
- ^b Factors are for filterable PM only. Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. Condensible organic and inorganic PM emission factors are not available. Factors presented can be considered a conservative underestimate of total PM.
- ^c Reference 12. EMISSION FACTOR RATING: E.
- ^d Reference 10.
- ^e References 10,13.
- ^f References 5,13. EMISSION FACTOR RATING: C.
- ^g Control device has no effect on emissions. See factor for uncontrolled emissions.
- ^h References 7,11.
- ^j Reference 9. For dried sand.
- ^k Reference 14. Screening of dried sand.

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EMISSION FACTOR RATING: D

	Pollutant		Emission factor		
Source	CASRN ^b	Name	kg/Mg	lb/ton	
Diesel-fired rotary sand dryer with fabric filter (SCC 3-05-027-22)	50-00-0 206-44-0 91-20-3 85-01-8	Formaldehyde Fluoranthene Naphthalene Phenanthrene	0.0021 3.0 x 10 ⁻⁶ 2.9 x 10 ⁻⁵ 7.5 x 10 ⁻⁶	0.0043 6.0 x 10 ⁻⁶ 5.9 x 10 ⁻⁵ 1.5 x 10 ⁻⁵	

^a Reference 8. Factors represent uncontrolled emissions unless noted. Dryer emission factors in units of kg/Mg and lb/ton of material dried. SCC = Source Classification Code.

^b Chemical Abstract Service Registry Number.

References For Section 11.19.1

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11.19.2 Crushed Stone Processing

11.19.2.1 Process Description¹⁻²

Major rock types processed by the rock and crushed stone industry include limestone, granite, dolomite, traprock, sandstone, quartz, and quartzite. Minor types include calcareous marl, marble, shell, and slate. Industry classifications vary considerably and, in many cases, do not reflect actual geological definitions.

Rock and crushed stone products generally are loosened by drilling and blasting, then are loaded by power shovel or front-end loader into large haul trucks that transport the material to the processing operations. Techniques used for extraction vary with the nature and location of the deposit. Processing operations may include crushing, screening, size classification, material handling, and storage operations. All of these processes can be significant sources of PM and PM-10 emissions if uncontrolled.

Quarried stone normally is delivered to the processing plant by truck and is dumped into a hoppered feeder, usually a vibrating grizzly type, or onto screens, as illustrated in Figure 11.19.2-1. The feeder or screens separate large boulders from finer rocks that do not require primary crushing, thus reducing the load to the primary crusher. Jaw, impactor, or gyratory crushers are usually used for initial reduction. The crusher product, normally 7.5 to 30 centimeters (3 to 12 inches) in diameter, and the grizzly throughs (undersize material) are discharged onto a belt conveyor and usually are conveyed to a surge pile for temporary storage, or are sold as coarse aggregates.

The stone from the surge pile is conveyed to a vibrating inclined screen called the scalping screen. This unit separates oversized rock from the smaller stone. The undersize material from the scalping screen is considered to be a product stream and is transported to a storage pile and sold as base material. The stone that is too large to pass through the top deck of the scalping screen is processed in the secondary crusher. Cone crushers are commonly used for secondary crushing (although impact crushers are sometimes used), which typically reduces material to about 2.5 to 10 centimeters (1 to 4 inches). The material (throughs) from the second level of the screen bypasses the secondary crusher because it is sufficiently small for the last crushing step. The output from the secondary crusher and the throughs from the secondary screen are transported by conveyor to the tertiary circuit, which includes a sizing screen and a tertiary crusher.

Tertiary crushing is usually performed using cone crushers or other types of impactor crushers. Oversize material from the top deck of the sizing screen is fed to the tertiary crusher. The tertiary crusher output, which is typically about 0.50 to 2.5 centimeters (3/16th to 1 inch), is returned to the sizing screen. Various product streams with different size gradations are separated in the screening operation. The products are conveyed or trucked directly to finished product bins, open area stockpiles, or to other processing systems such as washing, air separators, and screens and classifiers (for the production of manufactured sand).

Some stone crushing plants produce manufactured sand. This is a small-sized rock product with a maximum size of 0.50 centimeters (3/16th inch). Crushed stone from the tertiary sizing screen is sized in a vibrating inclined screen (fines screen) with relatively small mesh sizes. Oversized material is processed in a cone crusher or a hammermill (fines crusher) adjusted to produce small diameter material. The output is then returned to the fines screen for resizing.



Figure 11.19.2-1. Typical stone processing plant.² (SCC = Source Classification Code.)

EMISSION FACTORS

In certain cases, stone washing is required to meet particular end product specifications or demands as with concrete aggregate processing. Crushed and broken stone normally is not milled but is screened and shipped to the consumer after secondary or tertiary crushing.

11.19.2.2 Emissions And Controls¹⁻⁸

Emissions of PM and PM-10 occur from a number of operations in stone quarrying and processing. A substantial portion of these emissions consists of heavy particles that may settle out within the plant. As in other operations, crushed stone emission sources may be categorized as either process sources or fugitive dust sources. Process sources include those for which emissions are amenable to capture and subsequent control. Fugitive dust sources generally involve the reentrainment of settled dust by wind or machine movement. Emissions from process sources should be considered fugitive unless the sources are vented to a baghouse or are contained in an enclosure with a forced-air vent or stack. Factors affecting emissions from either source category include the stone size distribution and surface moisture content of the stone processed; the process throughput rate; the type of equipment and operating practices used; and topographical and climatic factors.

Of geographic and seasonal factors, the primary variables affecting uncontrolled PM emissions are wind and material moisture content. Wind parameters vary with geographical location, season, and weather. It can be expected that the level of emissions from unenclosed sources (principally fugitive dust sources) will be greater during periods of high winds. The material moisture content also varies with geographic location, season, and weather. Therefore, the levels of uncontrolled emissions from both process emission sources and fugitive dust sources generally will be greater in arid regions of the country than in temperate ones, and greater during the summer months because of a higher evaporation rate.

The moisture content of the material processed can have a substantial effect on emissions. This effect is evident throughout the processing operations. Surface wetness causes fine particles to agglomerate on, or to adhere to, the faces of larger stones, with a resulting dust suppression effect. However, as new fine particles are created by crushing and attrition, and as the moisture content is reduced by evaporation, this suppressive effect diminishes and may disappear. Plants that use wet suppression systems (spray nozzles) to maintain relatively high material moisture contents can effectively control PM emissions throughout the process. Depending on the geographic and climatic conditions, the moisture content of mined rock may range from nearly zero to several percent. Because moisture content is usually expressed on a basis of overall weight percent, the actual moisture amount per unit area will vary with the size of the rock being handled. On a constant mass-fraction basis, the per-unit area moisture content varies inversely with the diameter of the rock. Therefore, the suppressive effect of the moisture depends on both the absolute mass water content and the size of the rock product. Typically, wet material contains 1.5 to 4 percent water or more.

A variety of material, equipment, and operating factors can influence emissions from crushing. These factors include (1) stone type, (2) feed size and distribution, (3) moisture content, (4) throughput rate, (5) crusher type, (6) size reduction ratio, and (7) fines content. Insufficient data are available to present a matrix of rock crushing emission factors detailing the above classifications and variables. Available data indicate that PM-10 emissions from limestone and granite processing operations are similar. Therefore, the emission factors developed from the emission data gathered at limestone and granite processing facilities are considered to be representative of typical crushed stone processing operations. Emission factors for filterable PM and PM-10 emissions from crushed stone processing operations are presented in Tables 11.19-1 (metric units) and 11.19-2 (English units).

Source ^b	Total Particulate Matter	EMISSION FACTOR RATING	Total PM-10 ^c	EMISSION FACTOR RATING
Screening (SCC 3-05-020-02,-03)	_d		0.0076°	С
Screening (controlled) (SCC 3-05-020-02-03)	_d		0.00042 ^e	С
Primary crushing (SCC 3-05-020-01)	0.00035 ^f	E	ND ^g	
Secondary crushing (SCC 3-05-020-02)	ND		ND ^g	
Tertiary crushing (SCC 3-05-020-03)	d		0.0012 ^h	с
Primary crushing (controlled) (SCC 3-05-020-01)	ND		ND ^g	
Secondary crushing (controlled) (SCC 3-05-020-02)	ND		ND ^g	
Tertiary crushing (controlled) (SCC 3-05-020-03)	d		0.00029 ^h	с
Fines crushing ^j (SCC 3-05-020-05)	_d		0.0075	Е
Fines crushing (controlled) ^j (SCC 3-05-020-05)	_ ^d		0.0010	Е
Fines screening ^j (SCC 3-05-020-21)	_ ^d		0.036	Е
Fines screening (controlled) ^j (SCC 3-05-020-21)	d		0.0011	E
Conveyor transfer point ^k (SCC 3-05-020-06)	d		0.00072	D
Conveyor transfer point (controlled) ^k (SCC 3-05-020-06)	d		2.4x10 ⁻⁵	D
Wet drilling: unfragmented stone ^m (SCC 3-05-020-10)	ND		4.0x10 ⁻⁵	E,
Truck unloading: fragmented stone ^m (SCC 3-05-020-31)	ND		8.0x10 ⁻⁶	E
Truck loadingconveyor: crushed stone ⁿ (SCC 3-05-020-32)	ND		5.0x10 ⁻⁵	E

Table 11.19.2-1 (Metric Units). EMISSION FACTORS FOR CRUSHED STONE PROCESSING OPERATIONS^a

^a Emission factors represent uncontrolled emissions unless noted. Emission factors in kg/Mg of material throughput. SCC = Source Classification Code. ND = no data.

- ^b Controlled sources (with wet suppression) are those that are part of the processing plant that employs current wet suppression technology similar to the study group. The moisture content of the study group without wet suppression systems operating (uncontrolled) ranged from 0.21 to 1.3 percent and the same facilities operating wet suppression sytems (controlled) ranged from 0.55 to 2.88 percent. Due to carry over or the small amount of moisture required, it has been shown that each source, with the exception of crushers, does not need to employ direct water sprays. Although the moisture content was the only variable measured, other process features may have as much influence on emissions from a given source. Visual observations from each source under normal operating conditions are probably the best indicator of which emission factor is most appropriate. Plants that employ sub-standard control measures as indicated by visual observations should use the uncontrolled factor with an appropriate control efficiency that best reflects the effectiveness of the controls employed.
- ^c Although total suspended particulate (TSP) is not a measurable property from a process, some states may require estimates of TSP emissions. No data are available to make these estimates. However, relative ratios in AP-42 Sections 13.2.2 and 13.2.4 indicate that TSP emission factors may be estimated by multiplying PM-10 by 2.1.

Table 11.19.2-1 (cont.).

- ^d Emission factors for total particulate are not presented pending a re-evaluation of the EPA Method 201a test data and/or results of emission testing. This re-evaluation is expected to be completed by July 1995. ^e References 9, 11, 15-16.
- ^f Reference 1.
- ^g No data available, but emission factors for PM-10 emission factors for tertiary crushing can be used as an upper limit for primary or secondary crushing.
- ^h References 10-11, 15-16.
- ^j Reference 12.
- ^k References 13-14.
- ^mReference 3.
- ⁿ Reference 4.

	Total	EMISSION		EMISSION
Source ^b	Particulate Matter	FACTOR RATING	Total PM-10 ^c	FACTOR RATING
Screening (SCC 3-05-020-02,-03)	d		0.015°	С
Screening (controlled) (SCC 3-05-020-02-03)	_d		0.00084 ^e	с
Primary crushing (SCC 3-05-020-01)	0.00070 ^f	E	ND ^g	
Secondary crushing (SCC 3-05-020-02)	ND		ND ^g	
Tertiary crushing (SCC 3-05-020-03)	_d		0.0024 ^h	с
Primary crushing (controlled) (SCC 3-05-020-01)	ND		ND ^g	NA
Secondary crushing (controlled) (SCC 3-05-020-02)	ND		ND ^g	NA
Tertiary crushing (controlled) (SCC 3-05-020-03)	d		0.00059 ^h	с
Fines crushing ⁱ (SCC 3-05-020-05)	d		0.015	E
Fines crushing (controlled) ^j (SCC 3-05-020-05)	_d		0.0020	Е
Fines screening ⁱ (SCC 3-05-020-21)	d		0.071	Е
Fines screening (controlled) ^j (SCC 3-05-020-21)	_d		0.0021	E
Conveyor transfer point ^k (SCC 3-05-020-06)	d		0.0014	D
Conveyor transfer point (controlled) ^k (SCC 3-05-020-06)	d		4.8x10 ⁻⁵	D
Wet drilling: unfragmented stone ^m (SCC 3-05-020-10)	ND		8.0x10 ⁻⁵	E
Truck unloading: fragmented stone ^m (SCC 3-05-020-31)	ND		1.6x10 ⁻⁵	Е
Truck loading-conveyor: crushed stone ⁿ (SCC 3-05-020-32)	ND		0.00010	Е

Table 11.19.2-2 (English Units). EMISSION FACTORS FOR CRUSHED STONE PROCESSING OPERATIONS^a

^a Emission factors represent uncontrolled emissions unless noted. Emission factors in lb/ton of material throughput. SCC = Source Classification Code. ND = no data.

- ^b Controlled sources (with wet suppression) are those that are part of the processing plant that employs current wet suppression technology similar to the study group. The moisture content of the study group without wet suppression systems operating (uncontrolled) ranged from 0.21 to 1.3 percent and the same facilities operating wet suppression systems (controlled) ranged from 0.55 to 2.88 percent. Due to carry over or the small amount of moisture required, it has been shown that each source, with the exception of crushers, does not need to employ direct water sprays. Although the moisture content was the only variable measured, other process features may have as much influence on emissions from a given source. Visual observations from each source under normal operating conditions are probably the best indicator of which emission factor is most appropriate. Plants that employ sub-standard control measures as indicated by visual observations should use the uncontrolled factor with an appropriate control efficiency that best reflects the effectiveness of the controls employed.
- ^c Although total suspended particulate (TSP) is not a measurable property from a process, some states may require estimates of TSP emissions. No data are available to make these estimates. However, relative ratios in AP-42 Sections 13.2.2 and 13.2.4 indicate that TSP emission factors may be estimated by multiplying PM-10 by 2.1.

Table 11.19.2-2 (cont.).

- ^d Emission factors for total particulate are not presented pending a re-evaluation of the EPA Method 201a test data and/or results of emission testing. This re-evaluation is expected to be completed by July 1995.
- ^e References 9, 11, 15-16.
- ^f Reference 1.
- ^g No data available, but emission factors for PM-10 emission factors for tertiary crushing can be used as an upper limit for primary or secondary crushing.
- ^h References 10-11, 15-16.
- ^j Reference 12.
- ^k References 13-14.
- ^m Reference 3.
- ⁿ Reference 4.

Emission factor estimates for stone quarry blasting operations are not presented here because of the sparsity and unreliability of available test data. While a procedure for estimating blasting emissions is presented in Section 11.9, Western Surface Coal Mining, that procedure should not be applied to stone quarries because of dissimilarities in blasting techniques, material blasted, and size of blast areas. Milling of fines is not included in this section as this operation is normally associated with nonconstruction aggregate end uses and will be covered elsewhere when information is adequate. Emission factors for fugitive dust sources, including paved and unpaved roads, materials handling and transfer, and wind erosion of storage piles, can be determined using the predictive emission factor equations presented in AP-42 Section 13.2.

References For Section 11.19.2

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11.20 Lightweight Aggregate Manufacturing

11.20.1 Process Description^{1,2}

Lightweight aggregate is a type of coarse aggregate that is used in the production of lightweight concrete products such as concrete block, structural concrete, and pavement. The Standard Industrial Classification (SIC) code for lightweight aggregate manufacturing is 3295; there currently is no Source Classification Code (SCC) for the industry.

Most lightweight aggregate is produced from materials such as clay, shale, or slate. Blast furnace slag, natural pumice, vermiculite, and perlite can be used as substitutes, however. To produce lightweight aggregate, the raw material (excluding pumice) is expanded to about twice the original volume of the raw material. The expanded material has properties similar to natural aggregate, but is less dense and therefore yields a lighter concrete product.

The production of lightweight aggregate begins with mining or quarrying the raw material. The material is crushed with cone crushers, jaw crushers, hammermills, or pugmills and is screened for size. Oversized material is returned to the crushers, and the material that passes through the screens is transferred to hoppers. From the hoppers, the material is fed to a rotary kiln, which is fired with coal, coke, natural gas, or fuel oil, to temperatures of about 1200°C (2200°F). As the material is heated, it liquefies and carbonaceous compounds in the material form gas bubbles, which expand the material; in the process, volatile organic compounds (VOC) are released. From the kiln, the expanded product (clinker) is transferred by conveyor into the clinker cooler where it is cooled by air, forming a porous material. After cooling, the lightweight aggregate is screened for size, crushed if necessary, stockpiled, and shipped. Figure 11.20-1 illustrates the lightweight aggregate manufacturing process.

Although the majority (approximately 90 percent) of plants use rotary kilns, traveling grates are also used to heat the raw material. In addition, a few plants process naturally occurring lightweight aggregate such as pumice.

11.20.2 Emissions And Controls¹

Emissions from the production of lightweight aggregate consist primarily of particulate matter (PM), which is emitted by the rotary kilns, clinker coolers, and crushing, screening, and material transfer operations. Pollutants emitted as a result of combustion in the rotary kilns include sulfur oxides (SO_x) , nitrogen oxides (NO_x) , carbon monoxide (CO), carbon dioxide (CO_2) , and VOCs. Chromium, lead, and chlorides also are emitted from the kilns. In addition, other metals including aluminum, copper, manganese, vanadium, and zinc are emitted in trace amounts by the kilns. However, emission rates for these pollutants have not been quantified. In addition to PM, clinker coolers emit CO₂ and VOCs. Emission factors for crushing, screening, and material transfer operations can be found in AP-42 Section 11.19.

Some lightweight aggregate plants fire kilns with material classified as hazardous waste under the Resource Conservation and Recovery Act. Emission data are available for emissions of hydrogen chloride, chlorine, and several metals from lightweight aggregate kilns burning hazardous waste. However, emission factors developed from these data have not been incorporated in this AP-42 section because the magnitude of emissions of these pollutants is largely a function of the waste fuel composition, which can vary considerably.


Figure 11.20-1. Process flow diagram for lightweight aggregate manufacturing.

Emissions from rotary kilns generally are controlled with wet scrubbers. However, fabric filters and electrostatic precipitators (ESP) are also used to control kiln emissions. Multiclones and settling chambers generally are the only types of controls for clinker cooler emissions.

Tables 11.20-1 and 11.20-2 summarize uncontrolled and controlled emission factors for PM emissions (both filterable and condensable) from rotary kilns and clinker coolers. Emission factors for SO_x , NO_x , CO, and CO_2 emissions from rotary kilns are presented in Tables 11.20-3 and 11.20-4, which also include an emission factor for CO_2 emissions from clinker coolers. Table 11.20-5 presents emission factors for total VOC (TVOC) emissions from rotary kilns. Size-specific PM emission factors for rotary kilns and clinker coolers are presented in Table 11.20-6.

EMISSION FACTORS

Table 11.20-1 (Metric Units). EMISSION FACTORS FOR LIGHTWEIGHT AGGREGATE PRODUCTION^a

		Filter	able ^b		Condensable PM ^c				
		PM	Pl	M-10	Ino	rganic	Organic		
Process	kg/Mg Of Feed	EMISSION FACTOR RATING	kg/Mg Of Feed	EMISSION FACTOR RATING	kg/Mg Of Feed	EMISSION FACTOR RATING	kg/Mg Of Feed	EMISSION FACTOR RATING	
Rotary kiln	65 ^d	D	ND		0.41 ^e	D	0.0080 ^f	D	
Rotary kiln with scrubber	0.39 ^g	С	0.15 ^h	D	0.10 ^h	D	0.0046 ^h	D	
Rotary kiln with fabric filter	0.13 ⁱ	С	ND		0.070 ^j	D	ND		
Rotary kiln with ESP	0.34 ^k	D	ND		0.015 ^k	D	ND		
Clinker cooler with settling chamber	0.14 ¹	D	0.055 ¹	D	0.0085 ¹	D	0.00034 ¹	D	
Clinker coller with multiclone	0.15 ^m	D	0.060 ^m	D	0.0013 ^m	D	0.0014 ^m	D	

^a Factors represent uncontrolled emissions unless otherwise noted. ND = no data.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.

^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d References 3,7,14. Average of 3 tests that ranged from 6.5 to 170 kg/Mg.

^e References 3,14.

f Reference 3.

- ^g References 3,5,10,12-14.
- ^h References 3,5.
- ⁱ References 7,14,17-19.
- ^j Reference 14.
- ^k References 15,16.
- ¹ References 3,6.
- ^m Reference 4.

Table 11.20-2 (English Units). EMISSION FACTORS FOR LIGHTWEIGHT AGGREGATE PRODUCTION^a

		Filterable ^b				Condensable PM ^c				
		PM	P	M-10	Ino	rganic	Organic			
Process	lb/ton Of Feed	EMISSION FACTOR RATING	lb/ton Of Feed	EMISSION FACTOR RATING	lb/ton Of Feed	EMISSION FACTOR RATING	lb/ton Of Feed	EMISSION FACTOR RATING		
Rotary kiln	130 ^d	D	ND		0.82 ^c	D	0.016 ^f	D		
Rotary kiln with scrubber	0.78 ^g	с	0.29 ^h	D	0.19 ^h	D	0.0092 ^h	D		
Rotary kiln with fabric filter	0.26 ⁱ	с	ND		0.14 ^j	D	ND			
Rotary kiln with ESP	0.67 ^k	D	ND		0.031 ^k	D	ND			
Clinker cooler with settling chamber	0.28 ¹	D	0.11 ¹	D	0.017 ^l	D	0.00067 ^l	D		
Clinker cooler with multiclone	0.30 ^m	D	0.12 ^m	D	0.0025 ^m	D	0.0027 ^m	D		

^a Factors represent uncontrolled emissions unless otherwise noted. ND = no data.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.

^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d References 3,7,14. Average of 3 tests that ranged from 13 to 340 lb/ton.

^e References 3,14.

^f Reference 3.

^g References 3,5,10,12-14.

^h References 3,5.

- ⁱ References 7,14,17-19.
- ^j Reference 14.
- ^k References 15,16.
- ¹ References 3,6.

^m Reference 4.

Table 11.20-3 (Metric Units). EMISSION FACTORS FOR LIGHTWEIGHT AGGREGATE PRODUCTION^a

		so _x	J	NO _x	(со		CO ₂
Process	kg/Mg Of Feed	EMISSION FACTOR RATING	kg/Mg Of Feed	EMISSION FACTOR RATING	kg/Mg Of Feed	EMISSION FACTOR RATING	kg/Mg Of Feed	EMISSION FACTOR RATING
Rotary kiln	2.8 ^b	С	ND		0.29 ^c	С	240 ^d	С
Rotary kiln with scrubber	1.7 ^e	С	1.0 ^f	D	ND		ND	
Clinker cooler with dry multicyclone	ND		ND	:	ND		22 ^g	D

^a Factors represent uncontrolled emissions unless otherwise noted. ND = no data.

^b References 3,4,5,8. ^c References 17,18,19.

^d References 3,4,5,12,13,14,17,18,19 ^e References 3,4,5,9.

^f References 3,4,5.

^g Reference 4.

Table 11.20-4 (English Units). EMISSION FACTORS FOR LIGHTWEIGHT AGGREGATE PRODUCTION^a

		SO _x		NO _x	со		CO ₂	
Process	lb/ton Of Feed	EMISSION FACTOR RATING	lb/ton Of Feed	EMISSION FACTOR RATING	lb/ton Of Feed	EMISSION FACTOR RATING	lb/ton Of Feed	EMISSION FACTOR RATING
Rotary kiln	5.6 ^b	С	ND		0.59°	С	480 ^d	С
Rotary kiln with scrubber	3.4 ^e	С	1.9 ^f	D	ND		ND	
Clinker cooler with dry multicyclone	ND		ND		ND		43 ^g	D

^a Factors represent uncontrolled emissions unless otherwise noted. ND = no data.

^b References 3,4,5,8.

^c References 17,18,19.

^d References 3,4,5,12,13,14,17,18,19

^e References 3,4,5,9.

^f References 3,4,5.

^g Reference 4.

Table 11.20-5 (Metric And English Units). EMISSION FACTORS FOR LIGHTWEIGHT AGGREGATE PRODUCTION^a

		TVOCs		
Process	kg/Mg Of Feed	lb/ton Of Feed	EMISSION FACTOR RATING	
Rotary kiln	ND	ND	D	
Rotary kiln with scrubber	0.39 ^b	0.78 ^b	D	

^a Factors represent uncontrolled emissions unless otherwise noted. ND = no data.

^b Reference 3.

Table 11.20-6 (Metric And English Units). PARTICULATE MATTER SIZE-SPECIFIC EMISSION FACTORS FOR EMISSIONS FROM ROTARY KILNS AND CLINKER COOLERS^a

		T T	
	Cumulative %	Emissior	Factor
Diameter, micrometers	Less Than Diameter	kg/Mg	lb/ton
Rotary Kiln With Scrubber	b		
2.5	35	0.10	0.20
6.0	46	0.13	0.26
10.0	50	0.14	0.28
15.0	55	0.16	0.31
20.0	57	0.16	0.32
Clinker Cooler With Settlin	ng Chamber ^c		
2.5	9	0.014	0.027
6.0	21	0.032	0.063
10.0	35	0.055	0.11
15.0	49	0.080	0.16
20.0	58	0.095	0.19
Clinker Cooler With Multi	clone ^d		
2.5	19	0.029	0.057
6.0	31	0.047	0.093
10.0	40	0.060	0.12
15.0	48	0.072	0.14
20.0	53	0.080	0.16

EMISSION FACTOR RATING: D

^a Emission factors based on total feed.

^b References 3,5. ^c References 3,6.

^d Reference 4.

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11.21 Phosphate Rock Processing

11.21.1 Process Description¹⁻⁵

The separation of phosphate rock from impurities and nonphosphate materials for use in fertilizer manufacture consists of beneficiation, drying or calcining at some operations, and grinding. The Standard Industrial Classification (SIC) code for phosphate rock processing is 1475. The 6-digit Source Classification Code (SCC) for phosphate rock processing is 3-05-019.

Because the primary use of phosphate rock is in the manufacture of phosphatic fertilizer, only those phosphate rock processing operations associated with fertilizer manufacture are discussed here. Florida and North Carolina accounted for 94 percent of the domestic phosphate rock mined and 89 percent of the marketable phosphate rock produced during 1989. Other states in which phosphate rock is mined and processed include Idaho, Montana, Utah, and Tennessee. Alternative flow diagrams of these operations are shown in Figure 11.21-1.

Phosphate rock from the mines is first sent to beneficiation units to separate sand and clay and to remove impurities. Steps used in beneficiation depend on the type of rock. A typical beneficiation unit for separating phosphate rock mined in Florida begins with wet screening to separate pebble rock that is larger than 1.43 millimeters (mm) (0.056 inch [in.]) or 14 mesh, and smaller than 6.35 mm (0.25 in.) from the balance of the rock. The pebble rock is shipped as pebble product. The material that is larger than 0.85 mm (0.033 in.), or 20 mesh, and smaller than 14 mesh is separated using hydrocyclones and finer mesh screens and is added to the pebble product. The fraction smaller than 20 mesh is treated by 2-stage flotation. The flotation process uses hydrophilic or hydrophobic chemical reagents with aeration to separate suspended particles.

Phosphate rock mined in North Carolina does not contain pebble rock. In processing this type of phosphate, 10-mesh screens are used. Like Florida rock, the fraction that is less than 10 mesh is treated by 2-stage flotation, and the fraction larger than 10 mesh is used for secondary road building.

The 2 major western phosphate rock ore deposits are located in southeastern Idaho and northeastern Utah, and the beneficiation processes used on materials from these deposits differ greatly. In general, southeastern Idaho deposits require crushing, grinding, and classification. Further processing may include filtration and/or drying, depending on the phosphoric acid plant requirements. Primary size reduction generally is accomplished by crushers (impact) and grinding mills. Some classification of the primary crushed rock may be necessary before secondary grinding (rod milling) takes place. The ground material then passes through hydrocyclones that are oriented in a 3-stage countercurrent arrangement. Further processing in the form of chemical flotation may be required. Most of the processes are wet to facilitate material transport and to reduce dust.

Northeastern Utah deposits are a lower grade and harder than the southeastern Idaho deposits and require processing similar to that of the Florida deposits. Extensive crushing and grinding is necessary to liberate phosphate from the material. The primary product is classified with 150- to 200-mesh screens, and the finer material is disposed of with the tailings. The coarser fraction is processed through multiple steps of phosphate flotation and then diluent flotation. Further processing may include filtration and/or drying, depending on the phosphoric acid plant requirements. As is the case for southeastern Idaho deposits, most of the processes are wet to facilitate material transport and to reduce dust.





Figure 11.21-1. Alternative process flow diagrams for phosphate rock processing.

EMISSION FACTORS

The wet beneficiated phosphate rock may be dried or calcined, depending on its organic content. Florida rock is relatively free of organics and is for the most part no longer dried or calcined. The rock is maintained at about 10 percent moisture and is stored in piles at the mine and/or chemical plant for future use. The rock is slurried in water and wet-ground in ball mills or rod mills at the chemical plant. Consequently, there is no significant emission potential from wet grinding. The small amount of rock that is dried in Florida is dried in direct-fired dryers at about 120°C (250°F), where the moisture content of the rock falls from 10 to 15 percent to 1 to 3 percent. Both rotary and fluidized bed dryers are used, but rotary dryers are more common. Most dryers are fired with natural gas or fuel oil (No. 2 or No. 6), with many equipped to burn more than 1 type of fuel. Unlike Florida rock, phosphate rock mined from other reserves contains organics and must be heated to 760 to 870°C (1400 to 1600°F) to remove them. Fluidized-bed calciners are most commonly used for this purpose, but rotary calciners are also used. After drying, the rock is usually conveyed to storage silos on weather-protected conveyors and, from there, to grinding mills. In North Carolina, a portion of the beneficiated rock is calcined at temperatures generally between 800 and 825°C (1480 and 1520°F) for use in "green" phosphoric acid production, which is used for producing super phosphoric acid and as a raw material for purified phosphoric acid manufacturing. To produce "amber" phosphoric acid, the calcining step is omitted, and the beneficiated rock is transferred directly to the phosphoric acid production processes. Phosphate rock that is to be used for the production of granular triple super phosphate (GTSP) is beneficiated, dried, and ground before being transferred to the GTSP production processes.

Dried or calcined rock is ground in roll or ball mills to a fine powder, typically specified as 60 percent by weight passing a 200-mesh sieve. Rock is fed into the mill by a rotary valve, and ground rock is swept from the mill by a circulating air stream. Product size classification is provided by a "revolving whizzer, which is mounted on top of the ball mill," and by an air classifier. Oversize particles are recycled to the mill, and product size particles are separated from the carrying air stream by a cyclone.

11.21.2 Emissions And Controls^{1,3-9}

The major emission sources for phosphate rock processing are dryers, calciners, and grinders. These sources emit particulate matter (PM) in the form of fine rock dust and sulfur dioxide (SO_2) . Beneficiation has no significant emission potential because the operations involve slurries of rock and water. The majority of mining operations in Florida handle only the beneficiation step at the mine; all wet grinding is done at the chemical processing facility.

Emissions from dryers depend on several factors including fuel types, air flow rates, product moisture content, speed of rotation, and the type of rock. The pebble portion of Florida rock receives much less washing than the concentrate rock from the flotation processes. It has a higher clay content and generates more emissions when dried. No significant differences have been noted in gas volume or emissions from fluid bed or rotary dryers. A typical dryer processing 230 megagrams per hour (Mg/hr) (250 tons per hour [ton/hr]) of rock will discharge between 31 and 45 dry normal cubic meters per second (dry normal m³/sec) (70,000 and 100,000 dry standard cubic feet per minute [dscfm]) of gas, with a PM loading of 1,100 to 11,000 milligrams per dry normal cubic meters (mg/nm³) (0.5 to 5 grains per dry standard cubic foot [gr/dscf]). Emissions from calciners consist of PM and SO₂ and depend on fuel type (coal or oil), air flow rates, product moisture, and grade of rock.

Phosphate rock contains radionuclides in concentrations that are 10 to 100 times the radionuclide concentration found in most natural material. Most of the radionuclides consist of uranium and its decay products. Some phosphate rock also contains elevated levels of thorium and its

daughter products. The specific radionuclides of significance include uranium-238, uranium-234, thorium-230, radium-226, radon-222, lead-210, and polonium-210.

The radioactivity of phosphate rock varies regionally, and within the same region the radioactivity of the material may vary widely from deposit to deposit. Table 11.21-1 summarizes data on radionuclide concentrations (specific activities) for domestic deposits of phosphate rock in picocuries per gram (pCi/g). Materials handling and processing operations can emit radionuclides either as dust or in the case of radon-222, which is a decay product of uranium-238, as a gas. Phosphate dust particles generally have the same specific activity as the phosphate rock from which the dust originates.

Table 11.21-1. RADIONUCLIDE CONCENTRATIONS OF DOMESTIC PHOSPHATE ROCK^a

Origin	Typical Concentration Values, pCi/g
Florida	48 to 143
Tennessee	5.8 to 12.6
South Carolina	267
North Carolina	5.86 ^b
Arkansas, Oklahoma	19 to 22
Western States	80 to 123

^a Reference 8, except where indicated otherwise. Specific activities in units of picocuries per gram. ^b Reference 9.

Scrubbers are most commonly used to control emissions from phosphate rock dryers, but electrostatic precipitators are also used. Fabric filters are not currently being used to control emissions from dryers. Venturi scrubbers with a relatively low pressure loss (3,000 pascals [Pa] [12 in. of water]) may remove 80 to 99 percent of PM 1 to 10 micrometers (μ m) in diameter, and 10 to 80 percent of PM less than 1 μ m. High-pressure-drop scrubbers (7,500 Pa [30 in. of water]) may have collection efficiencies of 96 to 99.9 percent for PM in the size range of 1 to 10 μ m and 80 to 86 percent for particles less than 1 μ m. Electrostatic precipitators may remove 90 to 99 percent of all PM. Another control technique for phosphate rock dryers is use of the wet grinding process. In this process, rock is ground in a wet slurry and then added directly to wet process phosphoric acid reactors without drying.

A typical 45 Mg/hr (50 ton/hr) calciner will discharge about 13 to 27 dry normal m^3 /sec (30,000 to 60,000 dscfm) of exhaust gas, with a PM loading of 0.5 to 5 gr/dscf. As with dryers, scrubbers are the most common control devices used for calciners. At least one operating calciner is equipped with a precipitator. Fabric filters could also be applied.

Oil-fired dryers and calciners have a potential to emit sulfur oxides when high-sulfur residual fuel oils are burned. However, phosphate rock typically contains about 55 percent lime (CaO), which reacts with the SO₂ to form calcium sulfites and sulfates and thus reduces SO₂ emissions. Dryers and calciners also emit fluorides.

A typical grinder of 45 Mg/hr (50 ton/hr) capacity will discharge about 1.6 to 2.5 dry normal m^3 /sec (3,500 to 5,500 dscfm) of air containing 1.14 to 11.4 g/dry normal m^3 (0.5 to 5.0 gr/dscf) of PM. The air discharged is "tramp air," which infiltrates the circulating streams. To avoid fugitive emissions of rock dust, these grinding processes are operated at negative pressure. Fabric filters, and sometimes scrubbers, are used to control grinder emissions. Substituting wet grinding for conventional grinding would reduce the potential for PM emissions.

Emissions from material handling systems are difficult to quantify because several different systems are used to convey rock. Moreover, a large part of the emission potential for these operations is fugitives. Conveyor belts moving dried rock are usually covered and sometimes enclosed. Transfer points are sometimes hooded and evacuated. Bucket elevators are usually enclosed and evacuated to a control device, and ground rock is generally conveyed in totally enclosed systems with well defined and easily controlled discharge points. Dry rock is normally stored in enclosed bins or silos, which are vented to the atmosphere, with fabric filters frequently used to control emissions.

Table 11.21-2 summarizes emission factors for controlled emissions of SO_2 from phosphate rock calciners and for uncontrolled emissions of CO and CO_2 from phosphate rock dryers and calciners. Emission factors for PM emissions from phosphate rock dryers, grinders, and calciners are presented in Tables 11.21-3 and 11.21-4. Particle size distribution for uncontrolled filterable PM emissions from phosphate rock dryers and calciners are presented in Table 11.21-5, which shows that the size distribution of the uncontrolled calciner emissions is very similar to that of the dryer emissions. Tables 11.21-6 and 11.21-7 summarize emission factors for emissions of water-soluble and total fluorides from phosphate rock dryers and calciners. Emission factors for controlled and uncontrolled radionuclide emissions from phosphate rock grinders also are presented in Tables 11.21-7. Emission factors for PM emissions from phosphate rock ore storage, handling, and transfer can be developed using the equations presented in Section 13.2.4.

Table 11.21-2 (Metric And English Units). EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING^a

	S	02	CO ₂		со	
Process	kg/Mg Of Total Feed	lb/ton Of Total Feed	kg/Mg Of Total Feed	lb/ton Of Total Feed	kg/Mg Of Total Feed	lb/ton Of Total Feed
Dryer (SCC 3-05-019-01)	ND	ND	43 ^b	86 ^b	0.17 ^c	0.34 ^c
Calciner with scrubber (SCC 3-05-019-05)	0.0034 ^d	0.0069	115 ^e	230 ^e	ND	ND

EMISSIONS FACTOR RATING: D

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data.

^b References 10,11.

^c Reference 10.

^d References 13,15.

^e References 14-22.

		Filterable PM ^b				Condensable PM ^c			
	F	PM	Pl	PM-10		Inorganic		ganic	
Process	kg/Mg Of Total Feed	EMISSION FACTOR RATING							
Dryer (SCC 3-05-019-01) ^d	2.9.	D	2.4	E	ND		ND		
Dryer with scrubber (SCC 3-05-019-01) ^e	0.035	D	ND		0.015	D	ND		
Dryer with ESP (SCC 3-05-019-01) ^d	0.016	D	ND		0.004	D	ND		
Grinder (SCC 3-05-019-02) ^d	0.8	С	ND		ND		ND		
Grinder with fabric filter (SCC 3-05-019-02) ^f	0.0022	D	ND		0.0011	D	ND		
Calciner (SCC 3-05-019-05) ^d	7.7	D	7.4	Е	ND		ND		
Calciner with scrubber (SCC 3-05-019-05)	0.10 ^g	С	ND		0.0079 ^g	С	0.044 ^h	D	
Transfer and storage (SCC 3-05-019-) ^d	2	Ε	ND		ND		ND		

Table 11.21-3 (Metric Units). EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING^a

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.

^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d Reference 1.

^e References 1,10-11.

^f References 1,11-12.

^g References 1,14-22.

^h References 14-22.

		Filterable PM ^b				Condensable PM ^c		
	F	'nΜ	PN	<i>v</i> I-10	Inoi	ganic	Organic	
Process	lb/ton Of Total Feed	EMISSION FACTOR RATING						
Dryer (SCC 3-05-019-01) ^d	5.7	D	4.8	Е	ND		ND	
Dryer with scrubber (SCC 3-05-019-01) ^e	0.070	D	ND		0.030	D	ND	
Dryer with ESP (SCC 3-05-019-01) ^d	0.033	D	ND		0.008	D	ND	
Grinder (SCC 3-05-0190-2) ^d	1.5	с	ND		ND		ND	
Grinder with fabric filter (SCC 3-05-019-02) ^f	0.0043	D	ND		0.0021	D	ND	
Calciner (SCC 3-05-019-05) ^d	15	D	15	Е	ND		ND	:
Calciner with scrubber (SCC 3-05-019-05)	0.20 ^g	С	ND		0.16 ^g	С	0.088 ^h	D
Transfer and storage (SCC 3-05-019) ^d	1	E	ND		ND		ND	

Table 11.21-4 (English Units). EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING^a

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.

^c Condensable PM is that PM collected in the impinger portion of a PM sampling train.

^d Reference 1.

^e References 8,10-11.

^f References 1,11-12.

^g References 1,14-22.

^h References 14-22.

Table 11.21-5. PARTICLE SIZE DISTRIBUTION OF FILTERABLE PARTICULATEEMISSIONS FROM PHOSPHATE ROCK DRYERS AND CALCINERS^a

EMISSION FACTOR RATING: E

	Percent Less Than Size					
Diameter, µm	Dryers	Calciners				
10	82	96				
5	60	81				
2	27	52				
1	11	26				
0.8	7	10				
0.5	3	5				

^a Reference 1.

7/93 (Reformatted 1/95)

	Fluoride, H ₂ O-Soluble		Fluoria	le, Total	Radionuclides ^b	
Process	kg/Mg Of Total Feed	EMISSION FACTOR RATING	kg/Mg Of Total Feed	EMISSION FACTOR RATING	pCi/Mg Of Total Feed	EMISSION FACTOR RATING
Dryer (SCC 3-05-019-01) ^c	0.00085	D	0.037	D	ND	
Dryer with scrubber (SCC 3-05-019-01) ^d	0.00048	D	0.0048	D	ND	
Grinder (SCC 3-05-019-02) ^e	ND		ND		800R	Е
Grinder with fabric filter (SCC 3-05-019-02) ^e	ND		ND		5.2R	Е
Calciner with scrubber (SCC 3-05-019-05) ^f	ND		0.00081	D	ND	

Table 11.21-6 (Metric Units). EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING^a

^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data.

^b R is the radionuclide concentration (specific activity) of the phosphate rock. In units of pCi/Mg of feed.

^c Reference 10.

^d References 10-11.

^e References 7-8.

^f Reference 1.

Table 11.21-7 (English Units). EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING^a

	Fluoride, H ₂ O-Soluble lb/ton EMISSION		Fluori	de, Total	Radionuclides ^b	
			lb/ton	EMISSION	pCi/ton	EMISSION
	Of Total	FACTOR	Of Total	FACTOR	Of Total	FACTOR
Process	Feed	RATING	Feed	RATING	Feed	RATING
Dryer (SCC 3-05-019-01) ^c	0.0017	D	0.073	D	ND	
Dryer with scrubber (SCC 3-05-019-01) ^d	0.00095	D	0.0096	D	ND	
Grinder (SCC 3-05-019-02) ^e	ND		ND		730R	E
Grinder with fabric filter (SCC 3-05-019-02) ^e	ND		ND		4.7R	E
Calciner with scrubber (SCC 3-05-019-05) ^f	ND		0.0016	D	ND	

 ^a Factors represent uncontrolled emissions unless otherwise noted. SCC = Source Classification Code. ND = no data.

^b R is the radionuclide concentration (specific activity) of the phosphate rock. In units of pCi/Mg of feed.

^c Reference 10.

^d References 10-11.

^e References 7-8.

^f Reference 1.

The new source performance standard (NSPS) for phosphate rock plants was promulgated in April 1982 (40 CFR 60 Subpart NN). This standard limits PM emissions and opacity for phosphate rock calciners, dryers, and grinders and limits opacity for handling and transfer operations. The national emission standard for radionuclide emissions from elemental phosphorus plants was promulgated in December 1989 (40 CFR 61 Subpart K). This standard limits emissions of polonium-210 from phosphate rock calciners and nodulizing kilns at elemental phosphorus plants and requires annual compliance tests.

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11.22 Diatomite Processing

11.22.1 Process Description¹⁻²

Diatomite is a chalky, sedimentary rock consisting mainly of an accumulation of skeletons remaining from prehistoric diatoms, which are single-celled, microscopic aquatic plants. The skeletons are essentially amorphous hydrated or opaline silica occasionally with some alumina. Diatomite is primarily used to filter food processing products such as beer, whiskey, and fruit juice, and to filter organic liquids such as solvents and oils. Diatomite also is often used as a filler in paint, paper, asphalt products, and plastic. The six-digit Source Classification Code (SCC) for diatomite processing is 3-05-026.

Most diatomite deposits are found at or near the earth's surface and can be mined by open pit methods or quarrying. Diatomite mining in the United States is all open pit, normally using some combination of bulldozers, scraper-carriers, power shovels, and trucks to remove overburden and the crude material. In most cases, fragmentation by drilling and blasting is not necessary. The crude diatomite is loaded on trucks and transported to the mill or to stockpiles. Figure 11.22-1 shows a typical process flow diagram for diatomite processing.

The processing of uncalcined or natural-grade diatomite consists of crushing and drying. Crude diatomite commonly contains as much as 40 percent moisture, in many cases over 60 percent. Primary crushing to aggregate size (normally done by a hammermill) is followed by simultaneous milling-drying, in which suspended particles of diatomite are carried in a stream of hot gases. Flash and rotary dryers are used to dry the material to a powder of approximately 15 percent moisture. Typical flash dryer operating temperatures range from 70° to 430°C (150° to 800°F). The suspended particles exiting the dryer pass through a series of fans, cyclones, and separators to a baghouse. These sequential operations separate the powder into various sizes, remove waste impurities, and expel the absorbed water. These natural-milled diatomite products are then bagged or handled in bulk without additional processing.

For filtration uses, natural grade diatomite is calcined by heat treatment in gas- or fuel oilfired rotary calciners, with or without a fluxing agent. Typical calciner operating temperatures range from 650° to 1200°C (1200° to 2200°F). For straight-calcined grades, the powder is heated in large rotary calciners to the point of incipient fusion, and thus, in the strict technical sense, the process is one of sintering rather than calcining. The material exiting the kiln then is further milled and classified. Straight calcining is used for adjusting the particle size distribution for use as a medium flow rate filter aid. The product of straight calcining has a pink color from the oxidation of iron in the raw material, which is more intense with increasing iron oxide content.

Further particle size adjustment is brought about by the addition of a flux, usually soda ash, before the calcining step. Added fluxing agent sinters the diatomite particles and increases the particle size, thereby allowing increased flow rate during liquid filtration. The resulting products are called "flux-calcined". Flux-calcining produces a white product, believed to be colored by the



Figure 11.22-1. Typical process flow diagram for diatomite processing.

conversion of iron to complex sodium-aluminum-iron silicates rather than to the oxide. Further milling and classifying follow calcining.

11.22.2 Emissions And Controls¹⁻²

The primary pollutant of concern in diatomite processing is particulate matter (PM) and PM less than 10 micrometers (PM-10). Particulate matter is emitted from crushing, drying, calcining, classifying, and materials handling and transfer operations. Emissions from dryers and calciners include products of combustion, such as carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), and sulfur oxides (SO_x), in addition to filterable and condensible PM. Table 11.22-1 summarizes the results of a trace element analysis for one type of finished diatomite. These elements may constitute a portion of the PM emitted by the sources listed above.

Wet scrubbers and fabric filters are the most commonly used devices to control emissions from diatomite dryers and calciners. No information is available on the type of emission controls used on crushing, classifying, and materials handling and transfer operations.

Because of a lack of available data, no emission factors for diatomite processing are presented.

Element ^a	ppm ^b	Element	ppm
Antimony*	2	Mercury*	0.3
Arsenic*	5	Molybdenum	5
Barium	30	Neodymium	20
Beryllium*	1	Nickel*	120
Bismuth	< 0.5	Niobium	5
Boron	100	Osmium	< 0.5
Bromine	20	Palladium	<1
Cadmium*	2	Platinum	<2
Cerium	10	Praseodymium	2
Cesium	5	Rhenium	< 0.5
Chlorine	400	Rhodium	< 0.5
Chromium*	100	Rubidium	10
Cobalt*	5	Ruthenium	<1
Copper	40	Samarium	2
Dysprosium	<1	Scandium	20
Erbium	< 0.5	Selenium*	10
Europium	1	Silver	< 0.5
Fluorine	50	Strontium	20
Gadolinium	<1	Tantalum	20
Gallium	5	Tellurium	<2
Germanium	< 10	Terbium	< 0.2
Gold	< 0.5	Thallium	< 0.5
Hafnium	< 0.5	Thorium	5
Holmium	< 0.2	Thulium	0.2
Indium	< 0.5	Tin	<1
Iodine	1	Tungsten	< 0.5
Iridium	< 0.5	Uranium	5
Lanthanum	10	Vanadium	200
Lead*	2	Ytterbium	< 0.5
Lithium	1	Yttrium	100
Lutetium	< 0.2	Zinc	< 10
Manganese*	60	Zirconium	20

TABLE 11.22-1. TRACE ELEMENT CONTENT OF FINISHED DIATOMITE²

^a Listed hazardous air pollutants indicated by an asterisk (*).
 ^b < indicates below detection limit.

References For Section 11.22

- 1. Calciners And Dryers In Mineral Industries Background Information For Proposed Standards, EPA-450/3-025a, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1985.
- 2. F. L. Kadey, "Diatomite", *Industrial Rocks And Minerals, Volume I*, Society Of Mining Engineers, New York, 1983.

11.23 Taconite Ore Processing

11.23.1 General¹

The taconite ore processing industry produces usable concentrations of iron-bearing material by removing nonferrous rock (gangue) from low-grade ore. The six-digit Source Classification Code (SCC) for taconite ore processing is 3-03-023. Table 11.23-1 lists the SCCs for taconite ore processing.

Taconite is a hard, banded, low-grade ore, and is the predominant iron ore remaining in the United States. Ninety-nine percent of the crude iron ore produced in the United States is taconite. If magnetite is the principal iron mineral, the rock is called magnetic taconite; if hematite is the principal iron mineral, the rock is called hematic taconite.

About 98 percent of the demand for taconite comes from the iron and steel industry. The remaining 2 percent comes mostly from the cement industry but also from manufacturers of heavy-medium materials, pigments, ballast, agricultural products, and specialty chemicals. Ninety-seven percent of the processed ore shipped to the iron and steel industry is in the form of pellets. Other forms of processed ore include sinter and briquettes. The average iron content of pellets is 63 percent.

11.23.2 Process Description^{2-5,41}

Processing of taconite consists of crushing and grinding the ore to liberate iron-bearing particles, concentrating the ore by separating the particles from the waste material (gangue), and pelletizing the iron ore concentrate. A simplified flow diagram of these processing steps is shown in Figure 11.23-1.

Liberation is the first step in processing crude taconite ore and consists mostly of crushing and grinding. The ore must be ground to a particle size sufficiently close to the grain size of the iron-bearing mineral to allow for a high degree of mineral liberation. Most of the taconite used today requires very fine grinding. Prior to grinding, the ore is dry-crushed in up to six stages, depending on the hardness of the ore. One or two stages of crushing may be performed at the mine prior to shipping the raw material to the processing facility. Gyratory crushers are generally used for primary crushing, and cone crushers are used for secondary and tertiary fine crushing. Intermediate vibrating screens remove undersize material from the feed to the next crusher and allow for closed-circuit operation of the fine crushers. After crushing, the size of the material is further reduced by wet grinding in rod mills or ball mills. The rod and ball mills are also in closed circuit with classification systems such as cyclones. An alternative to crushing is to feed some coarse ores directly to wet or dry semiautogenous or autogenous grinding mills (using larger pieces of the ore to grind/mill the smaller pieces), then to pebble or ball mills. Ideally, the liberated particles of iron minerals and barren gangue should be removed from the grinding circuits as soon as they are formed, with larger particles returned for further grinding.

Concentration is the second step in taconite ore processing. As the iron ore minerals are liberated by the crushing steps, the iron-bearing particles must be concentrated. Because only about 33 percent of the crude taconite becomes a shippable product for iron making, a large amount of gangue

Key ^a	Source	SCC
Α	Ore storage	3-03-023-05
В	Ore transfer	3-03-023-04
С	Primary crusher	3-03-023-01
D	Primary crusher return conveyor transfer	3-03-023-25
Ε	Secondary crushing line	3-03-023-27
F	Secondary crusher return conveyor transfer	3-03-023-28
G	Tertiary crushing	3-03-023-02
Н	Tertiary crushing line	3-03-023-30
Ι	Tertiary crushing line discharge conveyor	3-03-023-31
J	Screening	3-03-023-03
K	Grinder feed	3-03-023-34
L	Primary grinding	3-03-023-06
Μ	Classification	3-03-023-36
Ν	Magnetic separation	3-03-023-17
0	Secondary grinding	3-03-023-38
Р	Conveyor transfer to concentrator	3-03-023-41
Q	Concentrate storage	3-03-023-44
R	Bentonite storage	3-03-023-07
S	Bentonite transfer to blending	3-03-023-45
Т	Bentonite blending	3-03-023-08
U	Green pellet screening	3-03-023-47
V	Chip regrinding	3-03-023-11
W	Grate/kiln furnace feed	3-03-023-49
Χ	Straight grate furnace feed	3-03-023-79
Y	Vertical shaft furnace feed	3-03-023-69
Z	Hearth layer feed to furnace	3-03-023-48
AA	Grate/kiln, gas-fired, acid pellets	3-03-023-51
AB	Grate/kiln, gas-fired, flux pellets	3-03-023-52
AC	Grate/kiln, gas- and oil-fired, acid pellets	3-03-023-53
AD	Grate/kiln, gas- and oil-fired, flux pellets	3-03-023-54
AE	Grate/kiln, coke-fired, acid pellets	3-03-023-55
AF	Grate/kiln, coke-fired, flux pellets	3-03-023-56
AG	Grate/kiln, coke- and coal-fired, acid pellets	3-03-023-57
AH	Grate/kiln, coke- and coal-fired, flux pellets	3-03-023-58
AI	Grate/kiln, coal-fired, acid pellets	3-03-023-59
AJ	Grate/kiln, coal-fired, flux pellets	3-03-023-60
AK	Grate/kiln, coal- and oil-fired, acid pellets	3-03-023-61
AL	Grate/kiln, coal- and oil-fired, flux pellets	3-03-023-62
AM	Vertical shaft, gas-fired, top gas stack, acid pellets	3-03-023-71

 Table 11.23-1.
 KEY FOR SOURCE CLASSIFICATION CODES FOR TACONITE ORE PROCESSING

Kev ^a SourceSCCANVertical shaft, gas-fired, top gas stack, flux pellets3-03-023-72AOVertical shaft, gas-fired, bottom gas stack, acid pellets3-03-023-73APVertical shaft, gas-fired, bottom gas stack, flux pellets3-03-023-74AQStraight grate, gas-fired, acid pellets3-03-023-74AQStraight grate, gas-fired, flux pellets3-03-023-81ARStraight grate, oil-fired, acid pellets3-03-023-82ASStraight grate, oil-fired, flux pellets3-03-023-84AUStraight grate, coke-fired, acid pellets3-03-023-84AUStraight grate, coke-fired, flux pellets3-03-023-86AWStraight grate, coke-fired, flux pellets3-03-023-86AWStraight grate, coke- and gas-fired, flux pellets3-03-023-87AXStraight grate, coke- and gas-fired, flux pellets3-03-023-80AYGrate/kiln furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-71BBHearth layer screen3-03-023-72BCPellet scoreen3-03-023-72BCPellet storage bin loading3-03-023-73BCPellet storage bin loading3-03-023-74BHTertiary storage bin loading3-03-023-70BHTertiary storage bin loading3-03-023-72bHaul road, rock3-03-023-73bHaul road, rock3-03-023-74bTailings basin3-03			
ANVertical shaft, gas-fired, top gas stack, flux pellets3-03-023-72AOVertical shaft, gas-fired, bottom gas stack, acid pellets3-03-023-73APVertical shaft, gas-fired, bottom gas stack, flux pellets3-03-023-74AQStraight grate, gas-fired, acid pellets3-03-023-74AQStraight grate, gas-fired, acid pellets3-03-023-81ARStraight grate, oil-fired, acid pellets3-03-023-82ASStraight grate, oil-fired, acid pellets3-03-023-83ATStraight grate, cole-fired, flux pellets3-03-023-86AVStraight grate, coke-fired, flux pellets3-03-023-86AWStraight grate, coke- and gas-fired, acid pellets3-03-023-87AXStraight grate, coke- and gas-fired, flux pellets3-03-023-87AXStraight grate, coke- and gas-fired, flux pellets3-03-023-80AYGrate/kiln furnace discharge3-03-023-80AZVertical shaft furnace discharge3-03-023-93BCPellet cooler3-03-023-95BEPellet screen3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-	Key ^a	Source	SCC
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APVertical shaft, gas-fired, bottom gas stack, flux pellets3-03-023-74AQStraight grate, gas-fired, acid pellets3-03-023-81ARStraight grate, gas-fired, flux pellets3-03-023-82ASStraight grate, oil-fired, acid pellets3-03-023-83ATStraight grate, oil-fired, flux pellets3-03-023-84AUStraight grate, coke-fired, acid pellets3-03-023-85AVStraight grate, coke-fired, flux pellets3-03-023-86AWStraight grate, coke- and gas-fired, acid pellets3-03-023-86AWStraight grate, coke- and gas-fired, flux pellets3-03-023-86AYGrate/kiln furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-93BCPellet cooler3-03-023-95BEPellet cooler3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-98bHaul road, taconite3-03-023-98bHaul road, taconite3-03-023-99cTraveling grate feed3-03-023-99cTraveling grate feed3-03-023-10cIndurating furnace: gas-fired3-03-023-10cIndurating furnace: coal-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-13cI	AO	Vertical shaft, gas-fired, bottom gas stack, acid pellets	3-03-023-73
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AXStraight grate, coke- and gas-fired, flux pellets3-03-023-88AYGrate/kiln furnace discharge3-03-023-50AZVertical shaft furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-70BBHearth layer screen3-03-023-80BDPellet cooler3-03-023-93BCPellet screen3-03-023-95BEPellet storage bin loading3-03-023-96BGSecondary storage bin loading3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-97bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-99cTraveling grate feed3-03-023-99cTraveling grate feed3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: coal-fired3-03-023-13cKiln3-03-023-13cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	AW	Straight grate, coke- and gas-fired, acid pellets	3-03-023-87
AYGrate/kiln furnace discharge3-03-023-50AZVertical shaft furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-80BBHearth layer screen3-03-023-93BCPellet cooler3-03-023-15BDPellet screen3-03-023-95BEPellet transfer to storage3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-98bHaul road, rock3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-10cTraveling grate feed3-03-023-12cIndurating furnace: gas-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-13cKiln3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	AX	Straight grate, coke- and gas-fired, flux pellets	3-03-023-88
AZVertical shaft furnace discharge3-03-023-70BAStraight grate furnace discharge3-03-023-80BBHearth layer screen3-03-023-93BCPellet cooler3-03-023-15BDPellet screen3-03-023-95BEPellet transfer to storage3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-98bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-99cTraveling grate feed3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: coal-fired3-03-023-13cKiln3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	AY	Grate/kiln furnace discharge	3-03-023-50
BAStraight grate furnace discharge3-03-023-80BBHearth layer screen3-03-023-93BCPellet cooler3-03-023-15BDPellet screen3-03-023-95BEPellet transfer to storage3-03-023-96BGSecondary storage bin loading3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-98bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-99cTraveling grate feed3-03-023-10cIraveling furnace: gas-fired3-03-023-12cIndurating furnace: coal-fired3-03-023-13cKiln3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	AZ	Vertical shaft furnace discharge	3-03-023-70
BBHearth layer screen3-03-023-93BCPellet cooler3-03-023-15BDPellet screen3-03-023-95BEPellet transfer to storage3-03-023-16BFPellet storage bin loading3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-98bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: coal-fired3-03-023-13cKiln3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	BA	Straight grate furnace discharge	3-03-023-80
BCPellet cooler3-03-023-15BDPellet screen3-03-023-95BEPellet transfer to storage3-03-023-96BFPellet storage bin loading3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-98bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: coal-fired3-03-023-13cKiln3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	BB	Hearth layer screen	3-03-023-93
BDPellet screen3-03-023-95BEPellet transfer to storage3-03-023-16BFPellet storage bin loading3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-97bHaul road, rock3-03-023-98bHaul road, taconite3-03-023-21bNonmagnetic separation3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: coal-fired3-03-023-13cKiln3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	BC	Pellet cooler	3-03-023-15
BEPellet transfer to storage3-03-023-16BFPellet storage bin loading3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-98bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-99cIraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: coal-fired3-03-023-13cKiln3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	BD	Pellet screen	3-03-023-95
BFPellet storage bin loading3-03-023-96BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-98bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-99cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: coal-fired3-03-023-13cKiln3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	BE	Pellet transfer to storage	3-03-023-16
BGSecondary storage bin loading3-03-023-97BHTertiary storage bin loading3-03-023-98bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-09cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	BF	Pellet storage bin loading	3-03-023-96
BHTertiary storage bin loading3-03-023-98bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-09cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	BG	Secondary storage bin loading	3-03-023-97
bHaul road, rock3-03-023-21bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-99cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	BH	Tertiary storage bin loading	3-03-023-98
bHaul road, taconite3-03-023-22bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-09cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	b	Haul road, rock	3-03-023-21
bNonmagnetic separation3-03-023-18bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-09cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	b	Haul road, taconite	3-03-023-22
bTailings basin3-03-023-40bOther, not classified3-03-023-99cTraveling grate feed3-03-023-09cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	b	Nonmagnetic separation	3-03-023-18
bOther, not classified3-03-023-99cTraveling grate feed3-03-023-09cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	b	Tailings basin	3-03-023-40
cTraveling grate feed3-03-023-09cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	b	Other, not classified	3-03-023-99
cTraveling grate discharge3-03-023-10cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	с	Traveling grate feed	3-03-023-09
cIndurating furnace: gas-fired3-03-023-12cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	с	Traveling grate discharge	3-03-023-10
cIndurating furnace: oil-fired3-03-023-13cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	с	Indurating furnace: gas-fired	3-03-023-12
cIndurating furnace: coal-fired3-03-023-14cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	с	Indurating furnace: oil-fired	3-03-023-13
cKiln3-03-023-19cConveyors, transfer, and loading3-03-023-20	С	Indurating furnace: coal-fired	3-03-023-14
c Conveyors, transfer, and loading 3-03-023-20	с	Kiln	3-03-023-19
	С	Conveyors, transfer, and loading	3-03-023-20

Table 11.23-1. (cont.).

^aRefers to labels in Figure 11.23-1. ^bNot shown in Figure 11.23-1. ^cInactive code.



Figure 11.23-1. Process flow diagram for taconite ore processing. (Refer to Table 11.23-1 for Source Classification Codes)

EMISSION FACTORS

is generated. Magnetic separation and flotation are the most commonly used methods for concentrating taconite ore.

Crude ores in which most of the recoverable iron is magnetite (or, in rare cases, maghemite) are normally concentrated by magnetic separation. The crude ore may contain 30 to 35 percent total iron by assay, but theoretically only about 75 percent of this is recoverable magnetite. The remaining iron is discarded with the gangue.

Nonmagnetic taconite ores are concentrated by froth flotation or by a combination of selective flocculation and flotation. The method is determined by the differences in surface activity between the iron and gangue particles. Sharp separation is often difficult.

Various combinations of magnetic separation and flotation may be used to concentrate ores containing various iron minerals (magnetite and hematite, or maghemite) and wide ranges of mineral grain sizes. Flotation is also often used as a final polishing operation on magnetic concentrates.

Pelletization is the third major step in taconite ore processing. Iron ore concentrates must be coarser than about No. 10 mesh to be acceptable as blast furnace feed without further treatment. Finer concentrates are agglomerated into small "green" pellets, which are classified as either acid pellets or flux pellets. Acid pellets are produced from iron ore and a binder only, and flux pellets are produced by adding between 1 and 10 percent limestone to the ore and binder before pelletization. Pelletization generally is accomplished by tumbling moistened concentrate with a balling drum or balling disc. A binder, usually powdered bentonite, may be added to the concentrate to improve ball formation and the physical qualities of the "green" balls. The bentonite is mixed with the carefully moistened feed at 5 to 10 kilograms per megagram (kg/Mg) (10 to 20 pounds per ton [lb/ton]).

The pellets are hardened by a procedure called induration. The green balls are dried and heated in an oxidizing atmosphere at incipient fusion temperature of 1290° to 1400°C (2350° to 2550°F), depending on the composition of the balls, for several minutes and then cooled. The incipient fusion temperature for acid pellets falls in the lower region of this temperature range, and the fusion temperature for flux pellets falls in the higher region of this temperature range. The three general types of indurating apparatus currently used are the vertical shaft furnace, the straight grate, and the grate/kiln. Most large plants and new plants use the grate/kiln. Currently, natural gas is the most common fuel used for pellet induration, but heavy oil is used at a few plants, and coal and coke may also be used.

In the vertical shaft furnace, the wet green balls are distributed evenly over the top of the slowly descending bed of pellets. A stream of hot gas of controlled temperature and composition rises counter to the descending bed of pellets. Auxiliary fuel combustion chambers supply hot gases midway between the top and bottom of the furnace.

The straight grate furnace consists of a continuously moving grate, onto which a bed of green pellets is deposited. The grate passes through a firing zone of alternating up and down currents of heated gas. The fired pellets are cooled either on an extension of the grate or in a separate cooler. An important feature of the straight grate is the "hearth layer", which consists of a 10- to 15-centimeter (4-to 6-inch) thick layer of fired pellets that protects the grate. The hearth layer is formed by diverting a portion of the fired pellets exiting the firing zone of the furnace to a hearth layer screen, which removes the fines. These pellets then are conveyed back to the feed end of the straight grate and deposited on to the bare grate. The green pellets being fed to the furnace are deposited on the hearth layer prior to the burning zone of the furnace.

The grate/kiln apparatus consists of a continuous traveling grate followed by a rotary kiln. The grate/kiln product must be cooled in a separate cooler, usually an annular cooler with counter current airflow.

11.23.3 Emissions And Controls^{2-7,41}

Particulate matter (PM) emission sources in taconite ore processing plants are indicated in Figure 11.23-1. Taconite ore is handled dry through the initial stages of crushing and screening. All crushers, size classification screens, and conveyor transfer points are major points of PM emissions. Crushed ore is normally wet ground in rod and ball mills. Because the ore remains wet, PM emissions are insignificant for the rest of the process until the drying stage of induration. A few plants use dry autogenous or semi-autogenous grinding and have higher emissions than do conventional plants.

Emissions from crushing and conveying operations are generally controlled by a hood-and-duct system that leads to a cyclone, rotoclone, multiclone, scrubber, or fabric filter. The inlet of the control device will often be fed by more than one duct. Water sprays are also used to control emissions.

The first source of emissions in the pelletizing process is the transfer and blending of bentonite. Additional emission points in the pelletizing process include the main waste gas stream from the indurating furnace, pellet handling, furnace transfer points (grate feed and discharge), and annular coolers for plants using the grate/kiln furnace.

Induration furnaces generate sulfur dioxide (SO_2) . The SO₂ originates both from the fuel and the raw material (concentrate, binder, and limestone). Induration furnaces also emit combustion products such as nitrogen oxides (NO_x) , and carbon monoxide (CO). Because of the additional heating requirements, emissions of NO_x and SO_2 generally are higher when flux pellets are produced than when acid pellets are produced.

The combination of multicyclones and wet scrubbers is a common configuration for controlling furnace waste gas. The purpose of the multicyclones is to recover material from the drying gases as they pass from the preheat stage to the drying stage. The wet scrubber reduces concentrations of SO_2 and PM in the furnace waste gas. Minor emission sources, such as grate feed and discharge, are usually controlled by small wet scrubbers.

Annular coolers normally operate in stages. The exhaust of the first-stage cooler is vented to the indurating furnace as preheated combustion gas. The second and third stages generally are uncontrolled.

Particulate matter emissions also arise from ore mining operations. The largest source of PM in taconite ore mines is traffic on unpaved haul roads. Other significant PM emission sources at taconite mines are tailing basins and wind erosion. Although blasting is a notable emission source of the various fractions of PM, it is a short-term event, and most of the material settles quickly.

Emissions from taconite ore processing facilities constructed or modified after August 24, 1982 are regulated under 40 CFR 60, subpart LL, Standards of Performance for Metallic Mineral Processing Plants. The affected emission sources include crushers, screens, conveyors, conveyor transfer points, storage bins, enclosed storage areas, product packaging stations, and truck and rail loading and unloading stations. The regulation limits PM stack emissions from these sources to 0.05 grams per dry standard cubic meter (0.022 grains per dry standard cubic foot). In addition, the opacity of stack emissions for these sources is limited to 7 percent unless the stack is equipped with a wet scrubber,

and process fugitive emissions are limited to 10 percent. The standard does not affect emissions from indurating furnaces.

Table 11.23-2 presents the factors for PM emissions from taconite ore indurating furnaces. Factors for emissions of PM from taconite ore processing sources other than furnaces are presented in Table 11.23-3. Factors for emissions of SO_2 , NO_x , CO, and CO_2 from taconite ore processing are presented in Tables 11.23-4 and 11.23-5 for acid pellet and flux pellet production, respectively. Table 11.23-6 presents emission factors for other pollutants emitted from taconite ore indurating furnaces. Emission factors for fugitive dust sources associated with taconite ore processing can be estimated using the predictive equations found in Section 13.2 of AP-42, which includes, for the parameters used in the equations, values based on measurements at taconite ore processing facilities.

		Filter				
Source	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Condensible ^c	EMISSION FACTOR RATING
Natural gas-fired grate/kiln (SCC 3-03-023-51,-52)	7.4 ^d	D	0.63 ^e	E	0.022 ^f	D
Natural gas-fired grate/kiln, with multiclone (SCC 3-03-023-51,-52)	0.44 ^g	D	0.13 ^h	Е	NA	
Natural gas-fired grate/kiln, with wet scrubber (SCC 3-03-023-51,-52)	0.082 ^j	С	ND		0.0055 ^k	D
Natural gas/oil-fired grate/kiln (SCC 3-03-023-53,-54)	ND		ND		0.040 ^m	D
Natural gas/oil-fired grate/kiln, with ESP (SCC 3-03-023-53,-54)	0.017 ^m	E	ND		ND	
Coal/oil-fired grate/kiln, with wet scrubber (SCC 3-03-023-61,-62)	0.19 ⁿ	E	ND		ND	
Coke-fired grate/kiln, with wet scrubber (SCC 3-03-023-55,-56)	0.10 ^p	Е	ND		ND	
Coke/coal-fired grate/kiln, with wet scrubber (SCC 3-03-023-57,-58)	0.14 ^q	D	ND		ND	
Gas-fired vertical shaft top gas stack (SCC 3-03-023-71,-72)	16 ^r	D	ND		ND	
Gas-fired vertical shaft top gas stack, with multiclone (SCC 3-03-023-71,-72)	1.4 ^s	D	ND		ND	
Gas-fired vertical shaft top gas stack, with wet scrubber (SCC 3-03-023-71,-72)	0.92 ^t	Е	ND		0.050 ^t	Е
Gas-fired vertical shaft top gas stack, with multiclone and wet scrubber (SCC 3-03-023-71,-72)	0.66 ^u	D	ND		ND	
Gas-fired vertical shaft bottom gas stack, with rotoclone (SCC 3-03-023-73,-74)	0.031 ^t	E	ND		0.0086 ^t	E
Oil-fired straight grate (SCC 3-03-023-83,-84)	1.2 ^v	Е	ND		ND	
Coke/gas-fired straight grate, with wet scrubber (SCC 3-03-023-83,-84)	0.11 ^w	D	ND		ND	

Table 11.23-2. EMISSION FACTORS FOR TACONITE ORE INDURATING FURNACES^a

- ^a Applicable to both acid pellets and flux pellets. Emission factors in units of lb/ton of fired pellets produced. One lb/ton is equivalent to 0.5 kg/Mg. Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data.
- ^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 sampling train or equivalent.
- ^c Condensible PM is that PM collected in the impinger portion of a PM sampling train.
- ^d References 4-5,40.
- ^e Reference 40.
- ^f References 4,36,39-40. Based on data presented in Reference 40, 84 percent of condensibles consists of inorganic material.
- ^g References 32-36,39,42-43.
- ^h Reference 39.
- ^j References 20,27,37.
- ^k References 4,37.
- ^m Reference 5.
- ⁿ Reference 18.
- ^p Reference 29.
- ^q References 26-27.
- ^r References 12-14,24.
- ^s References 12-13,24.
- ^t Reference 45.
- ^u Reference 14.
- ^v Reference 6.
- ^w References 30-31.

		Filterabl				
Source	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Condensible ^c	EMISSION FACTOR RATING
Primary crusher, with cyclone (SCC 3-03-023-01)	0.25 ^d	E	ND		ND	
Primary crusher, with cyclone and multiclone (SCC 3-03-023-01)	0.060 ^d	Е	ND		ND	
Primary crusher, with wet scrubber (SCC 3-03-023-01)	0.0012 ^e	E	ND		ND	
Primary crusher, with fabric filter (SCC 3-03-023-01)	0.0019 ^f	Е	ND		ND	
Secondary crushing line, with wet scrubber (SCC 3-03-023-27)	0.0027 ^g	E	ND		ND	
Tertiary crusher, with rotoclone (SCC 3-03-023-02)	0.0013 ^h	E	ND		ND	
Tertiary crushing line, with wet scrubber (SCC 3-03-023-30)	0.0016 ^g	D	ND		ND	
Grinder feed, with wet scrubber (SCC 3-03-023-34)	0.0011 ^j	С	ND		ND	
Hearth layer feed, with wet scrubber (SCC 3-03-023-48)	0.017 ^k	D	ND		ND	
Hearth layer screen, with wet scrubber (SCC 3-03-023-93)	0.038 ^m	Е	ND		ND	
Grate/kiln feed, with wet scrubber (SCC 3-03-023-49)	6.6 x 10 ^{-5(g)}	Е	ND		ND	
Grate/kiln discharge (SCC 3-03-023-50)	0.82 ⁿ	D	ND		0.00035 ^p 9.0 x 10 ^{-5 (q)}	E E
Grate/kiln discharge, with wet scrubber (SCC 3-03-023-50)	0.0019 ^r	Е	ND		0.00012 ^q	Е
Straight grate feed (SCC 3-03-023-79)	0.63 ^s	Ε	ND		ND	
Straight grate discharge (SCC 3-03-023-80)	1.4 ^s	E	ND		ND	
Straight grate discharge, with wet scrubber (SCC 3-03-023-80)	0.012 ^k	D	ND		ND	
Pellet cooler (SCC 3-03-023-15)	0.12 ^t	D	ND		ND	
Pellet screen (SCC 3-03-023-95)	1 10 ^u	E	I _{ND}	I	I ND	I

Table 11.23-3. EMISSION FACTORS FOR TACONITE ORE PROCESSING--OTHER SOURCES^a

EMISSION FACTORS

Table 11.23-3 (cont.).

		Filterabl				
Source	PM	EMISSION FACTOR RATING	P M- 10	EMISSION FACTOR RATING	Condensible ^c	EMISSION FACTOR RATING
Pellet screen, with rotoclone (SCC 3-03-023-95)	0.037 ^u	Е	ND		ND	
Primary crusher return conveyor transfer, with wet scrubber (SCC 3-03-023-25)	0.00031 ^f	Е	ND		ND	
Pellet transfer to storage, with wet scrubber (SCC 3-03-023-16)	0.00 36^m	Е	ND		ND	
Secondary crusher return conveyor transfer, with wet scrubber (SCC 3-03-023-28)	0.0057 ^v	D	ND		ND	
Conveyor transfer to concentrator, with wet scrubber (SCC 3-03-023-41)	0.00028 ^g	Е	ND		ND	
Tertiary crushing line discharge conveyor, with wet scrubber (SCC 3-03-023-31)	0.0017 ^g	E	ND		ND	
Bentonite storage bin loading, with wet scrubber (SCC 3-03-023-07)	2.4 ^m	Е	ND		ND	
Bentonite transfer (SCC 3-03-023-45)	3.2 ^s	E	ND		ND	
Bentonite transfer, with wet scrubber (SCC 3-03-023-45)	0.11 ^s	Е	ND		ND	
Bentonite blending (SCC 3-03-023-08)	19 ^s	E	ND		ND	
Bentonite blending, with wet scrubber (SCC 3-03-023-08)	0.25 ^s	Е	ND		ND	
Bentonite blending, with fabric filter (SCC 3-03-023-08)	0.11 ^s	E	ND		ND	
Pellet storage bin loading (SCC 3-03-023-96)	3.7 ^u	E	ND		ND	
Pellet storage bin loading, with rotoclone (SCC 3-03-023-96)	0.071 ^u	Е	ND		ND	
Secondary storage bin loading, with wet scrubber (SCC 3-03-023-97)	0.00019 ^g	Е	ND		ND	
Tertiary storage bin loading, with wet scrubber (SCC 3-03-023-98)	0.0018 ^g	D	ND		ND	

Table 11.23-3 (cont.).

- ^a Factors represent uncontrolled emissions unless noted. Emission factors for furnace feed, furnace discharge, coolers, and product handling are in units of lb/ton of pellets produced; emission factors for other sources are in units of lb/ton of material processed or handled. One lb/ton is equivalent to 0.5 kg/Mg. SCC = Source Classification Code. ND = no data available.
- ^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.
- ^c Condensible PM is that PM collected in the impinger portion of a PM sampling train.
- ^d References 10-11.
- ^e Reference 22.
- ^f Reference 27.
- ^g Reference 28.
- ^h Reference 6.
- ^J References 7,9.
- ^k References 8-9.
- ^m Reference 8.
- ⁿ References 4-5.
- ^p Reference 5.
- ^q Reference 4. Condensible inorganic PM fraction only.
- ^r Reference 4.
- ^s Reference 2.
- ^t References 16-17,27.
- ^u Reference 23.
- v References 21,28.

Source	SO2 ^b	EMISSION FACTOR RATING	NO _x	EMISSION FACTOR RATING	со	EMISSION FACTOR RATING	CO ₂ °	EMISSION FACTOR RATING
Natural gas-fired grate/kiln (SCC 3-03-023-51)	0.29 ^d	D	1.5°	D	0.014 ^f	D	99g	С
Natural gas-fired grate/kiln, with wet scrubber (SCC 3-03-023-51)	0.053 ^h	D	j		j		j	
Coke-fired grate/kiln (SCC 3-03-023-55)	1.9 ^k	Е	ND		ND		99 8	С
Coal/coke-fired grate/kiln, (SCC 3-03-023-57)	2.3 ^m	E	ND		ND		99 g	С
Coal/coke-fired grate/kiln, with wet scrubber (SCC 3-03-023-57)	1.5 ⁿ	D	ND		ND		j	
Gas-fired vertical shaft top gas stack (SCC 3-03-023-71)	ND		0.20 ^p	Е	0.077 ^p	Е	94 ^q	с
Gas-fired vertical shaft top gas stack, with wet scrubber (SCC 3-03-023-71)	0.28 ^p	Е	j		j		j	
Gas-fired straight grate (SCC 3-03-023-81)	ND		ND		0.0 3 9 ^r	Е	ND	
Gas-fired straight grate, with wet scrubber (SCC 3-03-023-81)	0.10 ^r	E	ND		j		ND	
Coke-fired straight grate, with multiclone and wet scrubber (SCC 3-03-023-85)	0.99 ^s	D	ND		j		ND	
Coke/gas-fired straight-grate (SCC 3-03-023-87)	ND		0.44 ^r	D	0.15 ^r	E	62 ^s	D

Table 11.23-4. EMISSION FACTORS FOR TACONITE ORE INDURATING FURNACES--ACID PELLET PRODUCTION^a

^a Emission factors in units of lb/ton of fired pellets produced. One lb/ton is equivalent to 0.5 kg/Mg.
 Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data.

^b Mass balance of sulfur may yield a more representative emission factor for a specific facility than the SO_2 factors presented in this table.

^c Mass balance on carbon may yield a more representative emission factor for a specific facility than the CO_2 factors represented in this table.

- ^d References 4,39-40.
- e References 19,27,39.
- f Reference 39.
- ^g References 5,18,29,32-34,39-40,42.
- ^h Reference 4.
- ¹ See emission factor for uncontrolled emissions.
- k Reference 29.
- ^m Reference 15.
- ⁿ References 15,25,29.
- ^p Reference 44.
- ^q References 12-14,24,44-45.
- r Reference 31.
- ^s References 30-31.

Ѕошсе	SO2 ^b	EMISSION FACTOR RATING	NO _x	EMISSION FACTOR RATING	со	EMISSION FACTOR RATING	CO ₂ °	EMISSION FACTOR RATING
Natural gas-fired grate/kiln, with wet scrubber (SCC 3-03-023-52)	0.14 ^d	D	1.5 ^e	D	0.10 ^f		130 ^g	С
Coal/coke-fired grate/kiln, with wet scrubber (SCC 3-03-023-58)	1.5 ^h	D	ND		ND		130 ^g	С
Gas-fired straight grate (SCC 3-03-023-82)	ND		2.5 ^j	D	ND		ND	
Pellet cooler (SCC 3-03-023-15)	Neg.		ND		ND		6.4 ^f	Е

Table 11.23-5. EMISSION FACTORS FOR TACONITE ORE INDURATING FURNACES--FLUX PELLET PRODUCTION^a

^a Emission factors in units of lb/ton of fired pellets produced. One lb/ton is equivalent to 0.5 kg/Mg. Factors represent uncontrolled emissions unless noted. SCC = Source Classification Code. ND = no data. Neg. = negligible.

^b Mass balance of sulfur may yield a more representative emission factor for a specific facility than the SO_2 factors presented in this table.

^c Mass balance on carbon may yield a more representative emission factor for a specific facility than the CO_2 factors represented in this table.

^d Reference 20.

e References 19,27,39.

f Reference 27.

^g References 20,25-27,36-37.

^h References 15,25,29.

^j Reference 38.

Source	Pollutant	Emission factor, lb/ton	References
Gas-fired grate/kiln (SCC 3-03-023-51,-52)	VOC	0.0037 ^b 0.075 ^c	39 27
Gas-fired grate/kiln, with multiclone (SCC 3-03-023-51,-52)	Lead	0.00050	39
Coke-fired grate/kiln (SCC 3-03-023-55,-56)	H ₂ SO ₄	0.17	29
Coke-fired grate/kiln, with wet scrubber (SCC 3-03-023-55,-56)	H ₂ SO ₄	0.099	29
Gas-fired vertical shaft top gas stack (SCC 3-03-023-71,-72)	VOC	0.013 ^d	44
Gas-fired vertical shaft bottom gas stack (SCC 3-03-023-73,-74)	VOC	0.046 ^d	44
Gas-fired straight grate furnace, with multiclone and wet scrubber (SCC 3-03-023-81,-82)	Lead	6.8 x 10 ⁻⁵	31
Gas-fired straight grate furnace, with multiclone and wet scrubber (SCC 3-03-023-85,-86)	Beryllium	2.2 x 10 ⁻⁷	31
Coke/gas-fired straight grate furnace, with multiclone and wet scrubber (SCC 3-03-023-87,-88)	Lead	7.6 x 10 ⁻⁵	31
Coke/gas-fired straight grate furnace, with multiclone and wet scrubber (SCC 3-03-023-87,-88)	Beryllium	2.9 x 10 ⁻⁷	31

EMISSION FACTOR RATING: E

^a Factors represent uncontrolled emissions unless noted. All emission factors for furnaces in lb/ton of fired pellets produced. One lb/ton is equivalent to 0.5 kg/Mg. SCC = Source Classification Code. ND = no data available.

^b Based on Method 25A data. EMISSION FACTOR RATING: D.

^c Based on Method 25 data.

^d Based on Method 25A data.

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11.24 Metallic Minerals Processing

11.24.1 Process Description¹⁻⁶

Metallic mineral processing typically involves the mining of ore from either open pit or underground mines; the crushing and grinding of ore; the separation of valuable minerals from matrix rock through various concentration steps; and at some operations, the drying, calcining, or pelletizing of concentrates to ease further handling and refining. Figure 11.24-1 is a general flow diagram for metallic mineral processing. Very few metallic mineral processing facilities will contain all of the operations depicted in this figure, but all facilities will use at least some of these operations in the process of separating valued minerals from the matrix rock.

The number of crushing steps necessary to reduce ore to the proper size vary with the type of ore. Hard ores, including some copper, gold, iron, and molybdenum ores, may require as much as a tertiary crushing. Softer ores, such as some uranium, bauxite, and titanium/zirconium ores, require little or no crushing. Final comminution of both hard and soft ores is often accomplished by grinding operations using media such as balls or rods of various materials. Grinding is most often performed with an ore/water slurry, which reduces particulate matter (PM) emissions to negligible levels. When dry grinding processes are used, PM emissions can be considerable.

After final size reduction, the beneficiation of the ore increases the concentration of valuable minerals by separating them from the matrix rock. A variety of physical and chemical processes is used to concentrate the mineral. Most often, physical or chemical separation is performed in an aqueous environment, which eliminates PM emissions, although some ferrous and titaniferous minerals are separated by magnetic or electrostatic methods in a dry environment.

The concentrated mineral products may be dried to remove surface moisture. Drying is most frequently done in natural gas-fired rotary dryers. Calcining or pelletizing of some products, such as alumina or iron concentrates, is also performed. Emissions from calcining and pelletizing operations are not covered in this section.

11.24.2 Process Emissions⁷⁻⁹

Particulate matter emissions result from metallic mineral plant operations such as crushing and dry grinding ore, drying concentrates, storing and reclaiming ores and concentrates from storage bins, transferring materials, and loading final products for shipment. Particulate matter emission factors are provided in Tables 11.24-1 and 11.24-2 for various metallic mineral process operations including primary, secondary, and tertiary crushing; dry grinding; drying; and material handling and transfer. Fugitive emissions are also possible from roads and open stockpiles, factors for which are in Section 13.2.

The emission factors in Tables 11.24-1 and 11.24-2 are for the process operations as a whole. At most metallic mineral processing plants, each process operation requires several types of equipment. A single crushing operation likely includes a hopper or ore dump, screen(s), crusher, surge bin, apron feeder, and conveyor belt transfer points. Emissions from these various pieces of equipment are often ducted to a single control device. The emission factors provided in Tables 11.24-1 and 11.24-2 for primary, secondary, and tertiary crushing operations are for process units that are typical arrangements of the above equipment.



Figure 11.24-1. Process flow diagram for metallic mineral processing.

Table 11.24-1 (Metric Units). EMISSION FACTORS FOR METALLIC MINERALS PROCESSING^a

EMISSION FACTOR RATINGS: (A-E) Follow The Emission Factor

		Filtera	ble ^{b,c}	
Source	PM	RATING	PM-10	RATING
Low-moisture ore ^c				
Primary crushing (SCC 3-03-024-01) ^d	0.2	С	0.02	с
Secondary crushing (SCC 3-03-024-02) ^d	0.6	D	ND	
Tertiary crushing (SCC 3-03-024-03) ^d	1.4	Е	0.08	E
Wet grinding	Neg		Neg	
Dry grinding with air conveying and/or air classification (SCC 3-03-024-09) ^e	14.4	С	13	С
Dry grinding without air conveying and/or air classification (SCC 3-03-024-10) ^e	1.2	D	0.16	D
Drying-all minerals except titanium/zirconium sands (SCC 3-03-024-11) ^f	9.8	С	5.9	С
Drying-titanium/zirconium with cyclones (SCC 3-03-024-11) ^f	0.3	С	ND	С
Material handling and transfer-all minerals except bauxite (SCC 3-03-024-04) ^g	0.06	С	0.03	С
Material handling and transfer-bauxite/alumina (SCC 3-03-024-04) ^{g,h}	0.6	С	ND	
High-moisture ore ^c				
Primary crushing (SCC 3-03-024-05) ^d	0.01	С	0. 00 4	С
Secondary crushing (SCC 3-03-024-06) ^d	0.03	D	0.012	D
Tertiary crushing (SCC 3-03-024-07) ^d	0.03	Е	0.01	Е
Wet grinding	Neg		Neg	
Dry grinding with air conveying and/or air classification (SCC 3-03-024-09) ^e	14.4	С	13	С
Dry grinding without air conveying and/or air classification (SCC 3-03-024-10) ^e	1.2	D	0.16	D
Drying-all minerals except titanium/zirconium sands (SCC 3-03-024-11) ^f	9.8	С	5.9	С
Dryingtitanium/zirconium with cyclones (SCC 3-03-024-11) ^f	0.3	С	ND	
Material handling and transfer-all minerals except bauxite (SCC 3-03-024-08) ^g	0.005	С	0.002	С
Material handling and transfer-bauxite/alumina (SCC 3-03-024-08) ^{g,h}	ND		ND	

^a References 9-12; factors represent uncontrolled emissions unless otherwise noted; controlled emission factors are discussed in Section 11.24.3. All emission factors are in kg/Mg of material processed unless noted. SCC = Source Classification Code. Neg = negligible. ND = no data.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

^c Defined in Section 11.24.2.

- ^d Based on weight of material entering primary crusher.
- ^e Based on weight of material entering grinder; emission factors are the same for both low-moisture and high-moisture ore because material is usually dried before entering grinder.
- ^f Based on weight of material exiting dryer; emission factors are the same for both high-moisture and low-moisture ores; SO_x emissions are fuel dependent (see Chapter 1); NO_x emissions depend on burner design and combustion temperature (see Chapter 1).
- ^g Based on weight of material transferred; applies to each loading or unloading operation and to each conveyor belt transfer point.
- ^h Bauxite with moisture content as high as 15 to 18% can exhibit the emission characteristics of lowmoisture ore; use low-moisture ore emission factor for bauxite unless material exhibits obvious sticky, nondusting characteristics.

Table 11.24-2 (English Units). EMISSION FACTORS FOR METALLIC MINERALS PROCESSING^{a,b}

	Filterable ^{b,c}			
Source	РМ	RATING	PM-10	RATING
Low-moisture ore ^c		-		
Primary crushing (SCC 3-03-024-01) ^d	0.5	с	0.05	с
Secondary crushing (SCC 303-024-02) ^d	1.2	D	ND	
Tertiary crushing (SCC 3-03-024-03) ^d	2.7	Е	0.16	E
Wet grinding	Neg		Neg	
Dry grinding with air conveying and/or air classification (SCC 3-03-024-09) ^c	28.8	С	26	с
Dry grinding without air conveying and/or air classification (SCC 3-03-024-10) ^c	2.4	D	0.31	D
Dryingall minerals except titanium/zirconium sands (SCC 3-03-024-11) ^f	19.7	С	12	С
Drying-titanium/zirconium with cyclones (SCC 3-03-024-11) ^f	0.5	С	ND	с
Material handling and transfer-all minerals except bauxite (SCC 3-03-024-04) ^g	0.12	С	0.06	С
Material handling and transfer-bauxite/alumina (SCC 3-03-024-04) ^{g,h}	1.1	С	ND	
High-moisture ore ^c				
Primary crushing (SCC 3-03-024-05) ^d	0.02	С	0.009	С
Secondary crushing (SCC 3-03-024-06) ^d	0.05	D	0.02	D
Tertiary crushing (SCC 3-03-024-07) ^d	0.06	E	0.02	Е
Wet grinding	Neg		Neg	
Dry grinding with air conveying and/or air classification (SCC 3-03-024-09) ^e	28.8	С	26	с
Dry grinding without air conveying and/or air classification (SCC 3-03-024-10) ^c	2.4	D	0.31	D
Drying-all minerals except titanium/zirconium sands (SCC 3-03-024-11) ^f	19.7	С	12	С
Drying-titanium/zirconium with cyclones (SCC 3-03-024-11) ^f	0.5	С	ND	
Material handling and transfer-all minerals except bauxite (SCC 3-03-024-08) ^g	0.01	С	0.004	С
Material handling and transfer-bauxite/alumina (SCC 3-03-024-08) ^{g,h}	ND		ND	

EMISSION FACTOR RATINGS: (A-E) Follow The Emission Factor

^a References 9-12; factors represent uncontrolled emissions unless otherwise noted; controlled emission factors are discussed in Section 11.24.3. All emission factors are in lb/ton of material processed unless noted. SCC = Source Classification Code. Neg = negligible. ND = no data.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

^c Defined in Section 11.24.2.

^d Based on weight of material entering primary crusher.

- ^e Based on weight of material entering grinder; emission factors are the same for both low-moisture and high-moisture ore because material is usually dried before entering grinder.
- ^f Based on weight of material exiting dryer; emission factors are the same for both high-moisture and low-moisture ores; SO_x emissions are fuel dependent (see Chapter 1); NO_x emissions depend on burner design and combustion temperature (see Chapter 1).

^g Based on weight of material transferred; applies to each loading or unloading operation and to each conveyor belt transfer point.

^h Bauxite with moisture content as high as 15 to 18% can exhibit the emission characteristics of lowmoisture ore; use low-moisture ore emission factor for bauxite unless material exhibits obvious sticky, nondusting characteristics. Emission factors are provided in Tables 11.24-1 and 11.24-2 for two types of dry grinding operations: those that involve air conveying and/or air classification of material and those that involve screening of material without air conveying. Grinding operations that involve air conveying and air classification usually require dry cyclones for efficient product recovery. The factors in Tables 11.24-1 and 11.24-2 are for emissions after product recovery cyclones. Grinders in closed circuit with screens usually do not require cyclones. Emission factors are not provided for wet grinders because the high-moisture content in these operations can reduce emissions to negligible levels.

The emission factors for dryers in Tables 11.24-1 and 11.24-2 include transfer points integral to the drying operation. A separate emission factor is provided for dryers at titanium/zirconium plants that use dry cyclones for product recovery and for emission control. Titanium/zirconium sand-type ores do not require crushing or grinding, and the ore is washed to remove humic and clay material before concentration and drying operations.

At some metallic mineral processing plants, material is stored in enclosed bins between process operations. The emission factors provided in Tables 11.24-1 and 11.24-2 for the handling and transfer of material should be applied to the loading of material into storage bins and the transferring of material from the bin. The emission factor will usually be applied twice to a storage operation: once for the loading operation and once for the reclaiming operation. If material is stored at multiple points in the plant, the emission factor should be applied to each operation and should apply to the material being stored at each bin. The material handling and transfer factors do not apply to small hoppers, surge bins, or transfer points that are integral with crushing, drying, or grinding operations.

At some large metallic mineral processing plants, extensive material transfer operations with numerous conveyor belt transfer points may be required. The emission factors for material handling and transfer should be applied to each transfer point that is not an integral part of another process unit. These emission factors should be applied to each such conveyor transfer point and should be based on the amount of material transferred through that point.

The emission factors for material handling can also be applied to final product loading for shipment. Again, these factors should be applied to each transfer point, ore dump, or other point where material is allowed to fall freely.

Test data collected in the mineral processing industries indicate that the moisture content of ore can have a significant effect on emissions from several process operations. High moisture generally reduces the uncontrolled emission rates, and separate emission rates are provided for primary crushers, secondary crushers, tertiary crushers, and material handling and transfer operations that process high-moisture ore. Drying and dry grinding operations are assumed to produce or to involve only low-moisture material.

For most metallic minerals covered in this section, high-moisture ore is defined as ore whose moisture content, as measured at the primary crusher inlet or at the mine, is 4 weight percent or greater. Ore defined as high-moisture at the primary crusher is presumed to be high-moisture ore at any subsequent operation for which high-moisture factors are provided unless a drying operation precedes the operation under consideration. Ore is defined as low-moisture when a dryer precedes the operation under consideration or when the ore moisture at the mine or primary crusher is less than 4 weight percent. Separate factors are provided for bauxite handling operations because some types of bauxite with a moisture content as high as 15 to 18 weight percent can still produce relatively high emissions during material handling procedures. These emissions could be eliminated by adding sufficient moisture to the ore, but bauxite then becomes so sticky that it is difficult to handle. Thus, there is some advantage to keeping bauxite in a relatively dusty state, and the low-moisture emission factors given represent conditions fairly typical of the industry.

Particulate matter size distribution data for some process operations have been obtained for control device inlet streams. Since these inlet streams contain PM from several activities, a variability has been anticipated in the calculated size-specific emission factors for PM.

Emission factors for PM equal to or less than 10 μ m in aerodynamic diameter (PM-10) from a limited number of tests performed to characterize the processes are presented in Table 11.24-1.

In some plants, PM emissions from multiple pieces of equipment and operations are collected and ducted to a control device. Therefore, examination of reference documents is recommended before applying the factors to specific plants.

Emission factors for PM-10 from high-moisture primary crushing operations and material handling and transfer operations were based on test results usually in the 30 to 40 weight percent range. However, high values were obtained for high-moisture ore at both the primary crushing and the material handling and transfer operations, and these were included in the average values in the table. A similarly wide range occurred in the low-moisture drying operation.

Several other factors are generally assumed to affect the level of emissions from a particular process operation. These include ore characteristics such as hardness, crystal and grain structure, and friability. Equipment design characteristics, such as crusher type, could also affect the emissions level. At this time, data are not sufficient to quantify each of these variables.

11.24.3 Controlled Emissions⁷⁻⁹

Emissions from metallic mineral processing plants are usually controlled with wet scrubbers or baghouses. For moderate to heavy uncontrolled emission rates from typical dry ore operations, dryers, and dry grinders, a wet scrubber with pressure drop of 1.5 to 2.5 kilopascals (kPa) (6 to 10 inches of water) will reduce emissions by approximately 95 percent. With very low uncontrolled emission rates typical of high-moisture conditions, the percentage reduction will be lower (approximately 70 percent).

Over a wide range of inlet mass loadings, a well-designed and maintained baghouse will reduce emissions to a relatively constant outlet concentration. Such baghouses tested in the mineral processing industry consistently reduce emissions to less than 0.05 gram per dry standard cubic meter (g/dscm) (0.02 grains per dry standard cubic foot [gr/dscf]), with an average concentration of 0.015 g/dscm (0.006 gr/dscf). Under conditions of moderate to high uncontrolled emission rates of typical dry ore facilities, this level of controlled emissions represents greater than 99 percent removal of PM emissions. Because baghouses reduce emissions to a relatively constant outlet concentration, percentage emission reductions would be less for baghouses on facilities with a low level of uncontrolled emissions.

References For Section 11.24

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11.25 Clay Processing

11.25.1 Process Description¹⁻⁴

Clay is defined as a natural, earthy, fine-grained material, largely of a group of crystalline hydrous silicate minerals known as clay minerals. Clay minerals are composed mainly of silica, alumina, and water, but they may also contain appreciable quantities of iron, alkalies, and alkaline earths. Clay is formed by the mechanical and chemical breakdown of rocks. The six-digit Source Classification Codes (SCC) for clay processing are as follows: SCC 3-05-041 for kaolin processing, SCC 3-05-042 for ball clay processing, SCC 3-05-043 for fire clay processing, SCC 3-05-044 for bentonite processing, SCC 3-05-045 for fuller's earth processing, and SCC 3-05-046 for common clay and shale processing.

Clays are categorized into six groups by the U. S. Bureau Of Mines. The categories are kaolin, ball clay, fire clay, bentonite, fuller's earth, and common clay and shale. Kaolin, or china clay, is defined as a white, claylike material composed mainly of kaolinite, which is a hydrated aluminum silicate (Al₂O₃•2SiO₂•2H₂O), and other kaolin-group minerals. Kaolin has a wide variety of industrial applications including paper coating and filling, refractories, fiberglass and insulation, rubber, paint, ceramics, and chemicals. Ball clay is a plastic, white-firing clay that is composed primarily of kaolinite and is used mainly for bonding in ceramic ware, primarily dinnerware, floor and wall tile, pottery, and sanitary ware. Fire clays are composed primarily of kaolinite, but also may contain several other materials including diaspore, burley, burley-flint, ball clay, and bauxitic clay and shale. Because of their ability to withstand temperatures of 1500°C (2700°F) or higher, fire clays generally are used for refractories or to raise vitrification temperatures in heavy clay products. Bentonite is a clay composed primarily of smectite minerals, usually montmorillonite, and is used largely in drilling muds, in foundry sands, and in pelletizing taconite iron ores. Fuller's earth is defined as a nonplastic clay or claylike material that typically is high in magnesia and has specialized decolorizing and purifying properties. Fuller's earth, which is very similar to bentonite, is used mainly as absorbents of pet waste, oil, and grease. Common clay is defined as a plastic clay or claylike material with a vitrification point below 1100°C (2000°F). Shale is a laminated sedimentary rock that is formed by the consolidation of clay, mud, or silt. Common clay and shale are composed mainly of illite or chlorite, but also may contain kaolin and montmorillonite.

Most domestic clay is mined by open-pit methods using various types of equipment, including draglines, power shovels, front-end loaders, backhoes, scraper-loaders, and shale planers. In addition, some kaolin is extracted by hydraulic mining and dredging. Most underground clay mines are located in Pennsylvania, Ohio, and West Virginia, where the clays are associated with coal deposits. A higher percentage of fire clay is mined underground than other clays, because the higher quality fire clay deposits are found at depths that make open-pit mining less profitable.

Clays usually are transported by truck from the mine to the processing plants, many of which are located at or near the mine. For most applications, clays are processed by mechanical methods, such as crushing, grinding, and screening, that do not appreciably alter the chemical or mineralogical properties of the material. However, because clays are used in such a wide range of applications, it is often necessary to use other mechanical and chemical processes, such as drying, calcining, bleaching, blunging, and extruding to prepare the material for use. Primary crushing reduces material size from as much as one meter to a few centimeters in diameter and typically is accomplished using jaw or gyratory crushers. Rotating pan crushers, cone crushers, smooth roll crushers, toothed roll crushers, and hammer mills are used for secondary crushing, which further reduces particle size to 3 mm (0.1 in.) or less. For some applications, tertiary size reduction is necessary and is accomplished by means of ball, rod, or pebble mills, which are often combined with air separators. Screening typically is carried out by means of two or more multi-deck sloping screens that are mechanically or electromagnetically vibrated. Pug mills are used for blunging, and rotary, fluid bed, and vibrating grate dryers are used for drying clay materials. At most plants that calcine clay, rotary or flash calciners are used. However, multiple hearth furnaces often are used to calcine kaolin.

Material losses through basic mechanical processing generally are insignificant. However, material losses for processes such as washing and sizing can reach 30 to 40 percent. The most significant processing losses occur in the processing of kaolin and fuller's earth. The following paragraphs describe the steps used to process each of the six categories of clay. Table 11.25-1 summarizes these processes by clay type.

Kaolin -

Kaolin is both dry- and wet-processed. The dry process is simpler and produces a lower quality product than the wet process. Dry-processed kaolin is used mainly in the rubber industry, and to a lesser extent, for paper filling and to produce fiberglass and sanitary ware. Wet-processed kaolin is used extensively in the paper manufacturing industry. A process flow diagram for kaolin mining and dry processing is presented in Figure 11.25-1, and Figure 11.25-2 illustrates the wet processing of kaolin.

In the dry process, the raw material is crushed to the desired size, dried in rotary dryers, pulverized and air-floated to remove most of the coarse grit. Wet processing of kaolin begins with blunging to produce a slurry, which then is fractionated into coarse and fine fractions using centrifuges, hydrocyclones, or hydroseparators. At this step in the process, various chemical methods, such as bleaching, and physical and magnetic methods, may be used to refine the material. Chemical processing includes leaching with sulfuric acid, followed by the addition of a strong reducing agent such as hydrosulfite. Before drying, the slurry is filtered and dewatered by means of a filter press, centrifuge, rotary vacuum filter, or tube filter. The filtered dewatered slurry material may be shipped or further processed by drying in apron, rotary, or spray dryers. Following the drying step, the kaolin may be calcined for use as filler or refractory material. Multiple hearth furnaces are most often used to calcine kaolin. Flash and rotary calciners also are used.

Ball Clay -

Mined ball clay, which typically has a moisture content of approximately 28 percent, first is stored in drying sheds until the moisture content decreases to 20 to 24 percent. The clay then is shredded in a disintegrator into small pieces 1.3 to 2.5 centimeters (cm) (0.5 to 1 in.) in thickness. The shredded material then is either dried or ground in a hammer mill. Material exiting the hammer mill is mixed with water and bulk loaded as a slurry for shipping. Figure 11.25-3 depicts the process flow for ball clay processing.

Indirect rotary or vibrating grate dryers are used to dry ball clay. Combustion gases from the firebox pass through an air-to-air heat exchanger to heat the drying air to a temperature of approximately 300°C (570°F). The clay is dried to a moisture content of 8 to 10 percent. Following drying, the material is ground in a roller mill and shipped. The ground ball clay may also be mixed with water as a slurry for bulk shipping.

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Process	Kaolin	Ball Clay	Fire Clay	Bentonite	Fuller's Earth	Common Clay And Shale
Mining	X	X	X	x	x	x
Stockpiling	х	х	х	Х	x	x
Crushing	x	х	х	Х	x	x
Grinding	X	Х	х	X	X	x
Screening	x	-	x		x	x
Mixing	x	x		į		x
Blunging	x				X	x
Air flotation	x	х				
Slurrying	Х	Х				
Extruding					х	x
Drying	x		х	х	X	x
Calcining	х		х			
Packaging	х	х	х	Х	х	
Other	Water fraction- ation, magnetic separation, acid treatment, bleaching	Shredding, pulverizing	Weathering, blending	Cation exchange, granulating, air classifying	Dispersing	

Table 11.25-1. CLAY PROCESSING OPERATIONS

Fire Clay -

Figure 11.25-4 illustrates the process flow for fire clay processing. Mined fire clay first is transported to the processing plant and stockpiled. In some cases, the crude clay is weathered for 6 to 12 months, depending on the type of fire clay. Freezing and thawing break the material up, resulting in smaller particles and improved plasticity. The material then is crushed and ground. At this stage in the process, the clay has a moisture content of 10 to 15 percent. For certain applications, the clay is dried in mechanical dryers to reduce the moisture content of the material to 7 percent or less. Typically, rotary and vibrating grate dryers fired with natural gas or fuel oil are used for drying fire clay.

To increase the refractoriness of the material, fire clay often is calcined. Calcining eliminates moisture and organic material and causes a chemical reaction to occur between the alumina and silica in the clay, rendering a material (mullite) that is harder, denser, and more easily crushed than



Figure 11.25-1. Process flow diagram for kaolin mining and dry processing. (SCC = Source Classification Code.)



Figure 11.25-2. Process flow diagram for wet process kaolin for high grade products. (SCC = Source Classification Code.)

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Figure 11.25-3. Process flow diagram for ball clay processing. (SCC = Source Classification Code.)



Figure 11.25-4. Process flow diagram for fire clay processing. (SCC = Source Classification Code.)

Mineral Products Industry

uncalcined fire clay. After the clay is dried and/or calcined, the material is crushed, ground, and screened. After screening, the processed fire clay may be blended with other materials, such as organic binders, before to being formed in the desired shapes and fired.

Bentonite -

A flow diagram for bentonite processing is provided in Figure 11.25-5. Mined bentonite first is transported to the processing plant and stockpiled. If the raw clay has a relatively high moisture content (30 to 35 percent), the stockpiled material may be plowed to facilitate air drying to a moisture content of 16 to 18 percent. Stockpiled bentonite may also be blended with other grades of bentonite to produce a uniform material. The material then is passed through a grizzly and crusher to reduce the clay pieces to less than 2.5 cm (1 in.) in size. Next, the crushed bentonite is dried in rotary or fluid bed dryers fired with natural gas, oil, or coal to reduce the moisture content to 7 to 8 percent. The temperatures in bentonite dryers generally range from 900°C (1650°F) at the inlet to 100 to 200°C (210 to 390°F) at the outlet. The dried material then is ground by means of roller or hammer mills. At some facilities which produce specialized bentonite products, the material is passed through an air classifier after being ground. Soda ash also may be added to the processed material to improve the swelling properties of the clay.

Fuller's Earth -

A flow diagram for fuller's earth processing is provided in Figure 11.25-6. After being mined, fuller's earth is transported to the processing plant, crushed, ground, and stockpiled. Before drying, fuller's earth is fed into secondary grinders to reduce further the size of the material. At some plants, the crushed material is fed into a pug mill, mixed with water, and extruded to improve the properties needed for certain end products. The material then is dried in rotary or fluid bed dryers fired with natural gas or fuel oil. Drying reduces the moisture content to 0 to 10 percent from its initial moisture content of 40 to 50 percent. The temperatures in fuller's earth dryers depend on the end used of the product. For colloidal grades of fuller's earth, drying temperatures of approximately 150°C (300°F) are used, and for absorbent grades, drying temperatures of 650°C (1200°F) are typical. In some plants, fuller's earth is calcined rather than dried. In these cases, an operating temperature of approximately 675°C (1250°F) is used. The dried or calcined material then is ground by roller or hammer mills and screened.

Common Clay And Shale -

Figure 11.25-7 depicts common clay and shale processing. Common clay and shale generally are mined, processed, formed, and fired at the same site to produce the end product. Processing generally begins with primary crushing and stockpiling. The material then is ground and screened. Oversize material may be further ground to produce particles of the desired size. For some applications, common clay and shale are dried to reduce the moisture content to desired levels. Further processing may include blunging or mixing with water in a pug mill, extruding, and firing in a kiln, depending on the type of end product.

11.25.2 Emissions And Controls^{3,9-10}

The primary pollutants of concern in clay processing operations are particulate matter (PM) and PM less than 10 micrometers (PM-10). Particulate matter is emitted from all dry mechanical processes, such as crushing, screening, grinding, and materials handling and transfer operations. The emissions from dryers and calciners include products of combustion, such as carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), and sulfur oxides (SO_x), in addition to filterable and condensible PM. Volatile organic compounds associated with the raw materials and the fuel also may be emitted from drying and calcining.



Figure 11.25-5. Process flow diagram for bentonite processing. (SCC = Source Classification Code.)

Mineral Products Industry



Figure 11.25-6. Process flow diagram for fuller's earth processing. (SCC = Source Classification Code.)



Figure 11.25-7. Process flow diagram for common clay and shale processing. (SCC = Source Classification Code.)

Mineral Products Industry

Cyclones, wet scrubbers, and fabric filters are the most commonly used devices to control PM emissions from most clay processing operations. Cyclones often are used for product recovery from mechanical processes. In such cases, the cyclones are not considered to be an air pollution control device. Electrostatic precipitators also are used at some facilities to control PM emissions.

Tables 11.25-2 (metric units) and 11.25-3 (English units) present the emission factors for kaolin processing, and Table 11.25-4 presents particle size distributions for kaolin processing. Table 11.25-5 (metric and English units) presents the emission factors for ball clay processing. Emission factors for fire clay processing are presented in Tables 11.25-6 (metric units) and 11.25-7 (English units). Table 11.25-8 presents the particle size distributions for fire clay processing. Emission factors for bentonite processing are presented in Tables 11.25-9 (metric units) and 11.25-10 (English units), and Table 11.25-11 presents the particle size distribution for bentonite processing. Emission factors for processing common clay and shale to manufacture bricks are presented in AP-42 Section 11.3, "Bricks And Related Clay Products". No data are available for processing common clay and shale for other applications.

No data are available also for individual sources of emissions from fuller's earth processing operations. However, data from one fuller's earth plant indicate the following emission factors for combined sources controlled with multiclones and wet scrubbers: for fuller's earth dried from approximately 50 percent to approximately 12 percent, 0.69 kg/Mg (1.4 lb/ton) for filterable PM and 310 kg/Mg (610 lb/ton) for CO_2 emissions from a rotary dryer, rotary cooler, and packaging warehouse. For fuller's earth dried from approximately 12 percent to 1 to 2 percent, assume 0.32 kg/Mg (0.63 lb/ton) for filterable PM emissions from a rotary dryer, rotary cooler, grinding and screening operations, and packaging warehouse. It should be noted that the sources tested may not be representative of current fuller's earth processing operations.

Table 11.25-2 (Metric Units). EMISSION FACTORS FOR KAOLIN PROCESSING^a

Source	Filterable PM ^b	Filterable PM-10 ^c	CO ₂
Spray dryer with fabric filter (SCC 3-05-041-31)	0.12 ^d	ND	81 ^e
Apron dryer (SCC 3-05-041-32)	0.62 ^f	ND	140 ^f
Multiple hearth furnace (SCC 3-05-041-40)	17 ^g	8.2 ^g	140 ^g
Multiple hearth furnace with venturi scrubber (SCC 3-05-041-40)	0.12 ^g	ND	NA
Flash calciner (SCC 3-05-041-42)	550 ^g	280 ^g	260 ^g
Flash calciner with fabric filter (SCC 3-05-041-42)	0.028 ^g	0.023 ^g	NA

EMISSION FACTOR RATING: D

 ^a Factors are kg/Mg produced. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data. NA = not applicable, control device has negligible effects on CO₂ emissions.

CO₂ emissions.
 ^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Based on filterable PM emission factor and particle size data.

- ^d References 3,5.
- ^e Reference 5.
- ^f Reference 6.
- ^g Reference 8.

Table 11.25-3 (English Units). EMISSION FACTORS FOR KAOLIN PROCESSING^a

Source	Filterable PM ^b	Filterable PM-10 ^c	CO ₂
Spray dryer with fabric filter (SCC 3-05-041-31)	0.23 ^d	ND	160 ^e
Apron dryer (SCC 3-05-041-32)	1.2 ^f	ND	280 ^f
Multiple hearth furnace (SCC 3-05-041-40)	34 ^g	16 ^g	280 ^g
Multiple hearth furnace with venturi scrubber (SCC 3-05-041-40)	0.23 ^g	ND	NA
Flash calciner (SCC 3-05-041-42)	1,100 ^g	560 ^g	510 ^g
Flash calciner with fabric filter (SCC 3-05-041-42)	0.055 ^g	0.046 ^g	NA

EMISSION FACTOR RATING: D

^a Factors are kg/Mg produced. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data. NA = not applicable, control device has negligible effects on

 CO_2 emissions.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Based on filterable PM emission factor and particle size data.

^d References 3,5.

^e Reference 5.

^f Reference 6.

^g Reference 8.

Table 11.25-4. PARTICLE SIZE DISTRIBUTIONS FOR KAOLIN PROCESSING^a

	Cu	Cumulative Percent Less Than Size			
	Multiple Hearth Furnace,	Flash Calciner ((SCC 3-05-041-42)		
Particle Size, µm	Uncontrolled (SCC 3-05-041-40)	Uncontrolled	With Fabric Filter		
1.0	5.65	ND	26.93		
1.25	8.21	11.14	31.88		
2.5	22.99	25.32	55.29		
6.0	42.1	44.65	77.34		
10	47.22	50.87	88.31		
15	52.02	55.35	94.77		
20	56.61	59.45	96.56		

^a Reference 8. SCC = Source Classification Code. ND = no data.

Table 11.25-5 (Metric And English Units). EMISSION FACTORS FOR BALL CLAY PROCESSING^a

EMISSION FACTOR RATING: D

	Filterable PM ^b	
Source	kg/Mg	lb/ton
Vibrating grate dryer with fabric filter (SCC 3-05-042-33)	0.071	0.14

^a Reference 3. Factors are kg/Mg and lb/ton of ball clay processed. SCC = Source Classification Code.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

Table 11.25-6 (Metric Units). EMISSION FACTORS FOR FIRE CLAY PROCESSING^a

				Filterable ^b	
Process	SO ₂	NO _x	CO ₂	РМ	PM-10
Rotary dryer ^c (SCC 3-05-043-30)	ND	ND	15 ^b	33	8.1
Rotary dryer with cyclone ^c (SCC 3-05-043-30)	ND	ND	ND	5.6	2.6
Rotary dryer with cyclone and wet scrubber ^c (SCC 3-05-043-30)	ND	ND	ND	0.052	ND
Rotary calciner (SCC 3-05-043-40)	ND	ND	300°	62 ^d	14 ^e
Rotary calciner with multiclone (SCC 3-05-043-40)	ND	ND	ND	31 ^f	ND
Rotary calciner with multiclone and wet scrubber (SCC 3-05-043-40)	3.8 ^d	0.87 ^d	ND	0.15 ^d	0.031 ^e

EMISSION FACTOR RATING: D

^a Factors are kg/Mg of raw material feed. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.

^c Reference 11.

^d References 12-13.

^e Reference 12.

^f Reference 13.

Table 11.25-7 (English Units). EMISSION FACTORS FOR FIRE CLAY PROCESSING^a

				Filterable ^b	
Process	SO ₂	NO _x	CO ₂	РМ	PM-10
Rotary dryer ^c (SCC 3-05-043-30)	ND	ND	30	65	16
Rotary dryer with cyclone ^c (SCC 3-05-043-30)	ND .	ND	ND	11	5.1
Rotary dryer with cyclone and wet scrubber ^c (SCC 3-05-043-30)	ND	ND	ND	0.11	ND
Rotary calciner (SCC 3-05-043-40)	ND	ND	600°	120 ^d	30 ^e
Rotary calciner with multiclone (SCC 3-05-043-40)	ND	ND	ND	61 ^f	ND
Rotary calciner with multiclone and wet scrubber (SCC 3-05-043-40)	7.6 ^d	1.7 ^d	ND	0.30 ^d	0.062 ^e

EMISSION FACTOR RATING: D

^a Factors are kg/Mg of raw material feed. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train. PM-10 values are based on cascade impaction particle size distribution.

^c Reference 11.

^d References 12-13.

^e Reference 12.

^f Reference 13.

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Table 11.25-8. PARTICLE SIZE DISTRIBUTIONS FOR FIRE CLAY PROCESSING^a

	Uncontrolled	Multiclone Controlled	Cyclone Controlled	Cyclone/Scrubber Controlled
Diameter (µm)	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter	Cumulative % Less Than Diameter
Rotary Dryers (SC	C 3-05-043-30) ^b			
2.5	2.5	ND	14	ND
6.0	10	ND	31	ND
10.0	24	ND	46	ND
15.0	37	ND	60	ND
20.0	51	ND	68	ND
Rotary Calciners (S	SCC 3-05-43-40)°			
1.0	3.1	13	ND	31
1.25	4.1	14	ND	43
2.5	6.9	23	ND	46
6.0	17	39	ND	55
10.0	34	50	ND	69
15.0	50	63	ND	81
20.0	62	81	ND	91

EMISSION FACTOR RATING: D

^a For filterable PM only. SCC = Source Classification Code. ND = no data.

^b Reference 11.

^c References 12-13 (uncontrolled). Reference 12 (multiclone-controlled). Reference 13 (cyclone/scrubber-controlled).

Source	Filterable PM ^b	EMISSION FACTOR RATING	PM-10 ^c	EMISSION FACTOR RATING
Rotary dryer (SCC 3-05-044-30)	140	D	10	D
Rotary dryer with fabric filter (SCC 3-05-044-30)	0.050	D	0.037	D
Rotary dryer with ESP (SCC 3-05-044-30)	0.016	E	ND	

Table 11.25-9 (Metric Units). EMISSION FACTORS FOR BENTONITE PROCESSING^a

^a Reference 3. Factors are kg/Mg produced. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Based on filterable PM emission factor and particle size data.

Table 11.25-10 (English Units). EMISSION FACTORS FOR BENTONITE PROCESSING^a

Source	Filterable PM ^b	EMISSION FACTOR RATING	PM-10 ^c	EMISSION FACTOR RATING
Rotary dryer (SCC 3-05-044-30)	290	D	20	D
Rotary dryer with fabric filter (SCC 3-05-044-30)	0.10	D	0.074	D
Rotary dryer with ESP (SCC 3-05-044-30)	0.033	E	ND	

^a Reference 3. Factors are kg/Mg produced. Emissions are uncontrolled, unless noted. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

^c Based on filterable PM emission factor and particle size data.

	Cumulative Percent Less Than Size		
Particle Size, µm	Rotary Dryer, Uncontrolled (SCC 3-05-044-30)	Rotary Dryer With Fabric Filter (SCC 3-05-044-30)	
1.0	0.2	2.5	
1.25	0.3	3.0	
2.5	0.8	12	
6.0	2.2	44	
10.0	7.0	74	
15.0	12	92	
20.0	25	97	

Table 11.25-11. PARTICLE SIZE DISTRIBUTIONS FOR BENTONITE PROCESSING^a

^a Reference 3. SCC = Source Classification Code.

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11.26 Talc Processing

11.26.1 Process Description¹⁻⁹

Talc, which is a soft, hydrous magnesium silicate $(3Mg0.4Si0_2.H_20)$, is used in a wide range of industries including the manufacture of ceramics, paints, paper, and asphalt roofing. The end-uses for talc are determined by variables such as chemical and mineralogical composition, particle size and shape, specific gravity, hardness, and color. There is no Source Classification Code (SCC) for the source category.

Over 95 percent of the talc ore produced in the United States comes from open-pit mines. Mining operations usually consist of conventional drilling and blasting methods.

Figure 11.26-1 is a process flow diagram for a typical domestic talc plant. Talc ore generally is hauled to the plant by truck from a nearby mine. The ore is crushed, typically in a jaw crusher, and screened. The coarse (oversize) material then is returned to the crusher. Rotary drvers may be used to dry the material. Secondary grinding is achieved with pebble mills or roller mills, producing a product that is 44 to 149 micrometers (μ m) (325 to 100 mesh) in size. Some roller mills are designed to use heated air to dry the material as it is being ground. Hammer mills or steam- or compressed air-powered jet mills may be used to produce additional final products. Air classifiers (separators), generally in closed circuit with the mills, separate the material into coarse, coarse-plusfine, and fine fractions. The coarse and coarse-plus-fine fractions then are stored as products. The fines may be concentrated using a shaking table (tabling process) to separate product containing small quantities of nickel, iron, cobalt, or other minerals and then may undergo a one-step flotation process. The resultant talc slurry is dewatered and filtered prior to passing through a flash dryer. The flash-dried product is then stored for shipment, unless it needs further grinding to meet customer specifications. The classified material also may be pelletized prior to packaging for specific applications. In the pelletizing step, processed talc is mixed with water to form a paste and then is extruded as pellets.

Talc deposits mined in the southwestern United States contain organic impurities and must be calcined prior to additional processing to yield a product with uniform chemical and physical properties. Generally, a separate product will be used to produce the calcined talc. Prior to calcining, the mined ore passes through a crusher and is ground to a specified screen size. After calcining in a rotary kiln, the material passes through a rotary cooler. The cooled calcine (0 percent free water) is then either stored for shipment or further processed. Calcined talc may be mixed with dried talc from other product lines and passed through a roller mill prior to bulk shipping.

11.26.2 Emissions And Controls^{1-2,4-5,7-8,10-13}

The primary pollutants of concern in talc processing are particulate matter (PM) and PM less than 10 μ m (PM-10). Particulate matter is emitted from drilling, blasting, crushing, screening, grinding, drying, calcining, classifying, materials handling and transfer operations, packaging, and storage. Although pelletizing is a wet process, PM may be emitted from the transfer and feeding of processed talc to the pelletizer. Depending on the purity of the talc ore body, PM emissions may include trace amounts of several inorganic compounds that are listed hazardous air pollutants (HAP), including arsenic, cadmium, chromium, cobalt, manganese, nickel, and phosphorus.



Figure 11.26-1. Process flow diagram for talc processing.^{1,4,6} (Source Classification Codes in parentheses.)

The emissions from dryers and calciners include products of combustion, such as carbon monoxide, carbon dioxide, nitrogen oxides, and sulfur oxides, in addition to filterable and condensible PM. Volatile organic compounds also are emitted from the drying and calcining of southwestern United States talc deposits, which generally contain organic impurities. Products of combustion and VOC may also be emitted from roller mills that use heated air and from the furnaces that provide the heated air to the mill.

Emissions from talc dryers and calciners are typically controlled with fabric filters. Fabric filters also are used at some facilities to control emissions from mechanical processes such as crushing and grinding. Emission factors for emissions from talc processing are presented in Table 11.26-1. Particle size distributions for talc processing are summarized in Table 11.26-2 and are depicted graphically in Figure 11.26-2.
Table 11.26-1. EMISSION FACTORS FOR TALC PROCESSING^a

EMISSION FACTOR RATING: D

	Total PM ^b	CO ₂
Process	lb/1,000 lb	lb/1,000 lb
Natural gas-fired crude ore drying with fabric filter ^c (SCC 3-05-089-09)	0.0020	ND
Primary crushing, with fabric filter ^d (SCC 3-05-089-11)	0.00074	NA
Crushed talc railcar loading ^e (SCC 3-05-089-12)	0.00049	NA
Screening, with fabric filter ^f (SCC 3-05-089-17)	0.0043	NA
Grinding, with fabric filter ^g (SCC 3-05-089-45)	0.022	NA
Grinding with heated makeup air, with fabric filter (SCC 3-05-089-47)	0.022 ^g	9.3 ^h
Classifying, with fabric filter ^j (SCC 3-05-089-50)	0.00077	NA
Pellet drying, with fabric filter ^k (SCC 3-05-089-55)	0.032	ND
Pneumatic conveyor venting, with fabric filter ^m (SCC 3-05-089-58)	0.0018	NA
Packaging, with fabric filter ⁿ (SCC 3-05-089-88)	0.0090	NA
Crushed talc storage bin loading, with fabric filter ^p (SCC 3-05-089-14)	0.0036	NA
Ground talc storage bin loading, with fabric filter ^q (SCC 3-05-089-49)	0.0016	NA
Final product storage bin loading, with fabric filter ^p (SCC 3-05-089-85)	0.0035	NA

^a Units are lb/1,000 lb of production unless noted. One lb/1,000 lb is equal to 1 kg/Mg. SCC = Source Classification Code. NA = not applicable. ND = no data.

^b Total PM includes the PM collected in the front half and the inorganic PM caught in the back half (impingers) of a Method 5 sampling train.

- ^c Reference 15. Filterable PM fraction is 60%, and condensible inorganic fraction is 40%.
- ^d References 10,13,15.
- ^e Reference 14.
- ^f References 10,13. For crushed talc ore.
- ^g References 11,13.
- ^h References 10-11. For roller mill using heated makeup air. EMISSION FACTOR RATING: E.
- ^j Reference 13. For ground talc.
- ^k Reference 13. Filterable PM fraction is 56%, and condensible inorganic fraction is 44%. EMISSION FACTOR RATING: E.
- ^m Reference 13. For final product. Units are lb/1,000 lb of material conveyed.

- ^p Reference 13. Units are lb/1,000 lb of material loaded into storage bin.
- ^q Reference 12. Units are lb/1,000 lb of material loaded into storage bin.

EMISSION FACTORS

ⁿ Reference 10,13.

Process	Diameter, μm	Cumulative Percent Less Than Diameter
Primary crushing	55.4	91.3
(SCC 3-05-089-11)	34.9	78.2
	22.0	56.7
	17.4	47.2
	11.0	38.8
	6.9	21.4
	3.0	3.0
	2.0	0.94
	1.0	0.11
Grinding	29.0	. 100.0
(SCC 3-05-089-45)	18.8	99.7
	14.9	99.4
	11.9	97.1
	9.4	80.8
	7.5	43.3
	4.7	7.5
	3.0	2.1
	1.9	0.28
	1.0	0.04
Storage, bagging, air classification	43.9	99.9
(SCC 3-05-089-85,-88,-50)	27.7	97.9
	17.4	86.6
	13.8	73.2
	11.0	56.8
	6.9	24.5
	4.4	7.4
	3.0	3.1
	2.0	0.92
	1.0	0.10

Table 11.26-2.SUMMARY OF PARTICLE SIZE DISTRIBUTIONS FOR
TALC PROCESSING^a

^a Reference 5. Optical procedures used to determine particle size distribution, rather than inertial separators. Data are suspect. SCC = Source Classification Code.



Figure 11.26-2. Particle size distribution for talc processing.⁵

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11.27 Feldspar Processing

11.27.1 General¹

Feldspar consists essentially of aluminum silicates combined with varying percentages of potassium, sodium, and calcium, and it is the most abundant mineral of the igneous rocks. The two types of feldspar are soda feldspar (7 percent or higher Na₂O) and potash feldspar (8 percent or higher K_2O). Feldspar-silica mixtures can occur naturally, such as in sand deposits, or can be obtained from flotation of mined and crushed rock.

11.27.2 Process Description ¹⁻²

Conventional open-pit mining methods including removal of overburden, drilling and blasting, loading, and transport by trucks are used to mine ores containing feldspar. A froth flotation process is used for most feldspar ore beneficiation. Figure 11.27-1 shows a process flow diagram of the flotation process. The ore is crushed by primary and secondary crushers and ground by jaw crushers, cone crushers, and rod mills until it is reduced to less than 841 μ m (20 mesh). Then the ore passes to a three-stage, acid-circuit flotation process.

An amine collector that floats off and removes mica is used in the first flotation step. Also, sulfuric acid, pine oil, and fuel oil are added. After the feed is dewatered in a classifier or cyclone to remove reagents, sulfuric acid is added to lower the pH. Petroleum sulfonate (mahogany soap) is used to remove iron-bearing minerals. To finish the flotation process, the discharge from the second flotation step is dewatered again, and a cationic amine is used for collection as the feldspar is floated away from quartz in an environment of hydrofluoric acid (pH of 2.5 to 3.0).

If feldspathic sand is the raw material, no size reduction may be required. Also, if little or no mica is present, the first flotation step may be bypassed. Sometimes the final flotation stage is omitted, leaving a feldspar-silica mixture (often referred to as sandspar), which is usually used in glassmaking.

From the completed flotation process, the feldspar float concentrate is dewatered to 5 to 9 percent moisture. A rotary dryer is then used to reduce the moisture content to 1 percent or less. Rotary dryers are the most common dryer type used, although fluid bed dryers are also used. Typical rotary feldspar dryers are fired with No. 2 oil or natural gas, operate at about 230°C (450° F), and have a retention time of 10 to 15 minutes. Magnetic separation is used as a backup process to remove any iron minerals present. Following the drying process, dry grinding is sometimes performed to reduce the feldspar to less than 74 μ m (200 mesh) for use in ceramics, paints, and tiles. Drying and grinding are often performed simultaneously by passing the dewatered cake through a rotating gas-fired cylinder lined with ceramic blocks and charged with ceramic grinding balls. Material processed in this manner must then be screened for size or air classified to ensure proper particle size.

11.27.2 Emissions And Controls

The primary pollutant of concern that is emitted from feldspar processing is particulate matter (PM). Particulate matter is emitted by several feldspar processing operations, including crushing, grinding, screening, drying, and materials handling and transfer operations.



Figure 11.27-1. Feldspar flotation process.¹

EMISSION FACTORS

Emissions from dryers typically are controlled by a combination of a cyclone or a multiclone and a scrubber system. Particulate matter emissions from crushing and grinding generally are controlled by fabric filters.

Table 11.27-1 presents controlled emission factors for filterable PM from the drying process. Table 11.27-2 presents emission factors for CO_2 from the drying process. The controls used in feldspar processing achieve only incidental control of CO_2 .

Table 11.27-1 (Metric And English Units). EMISSION FACTORS FOR FILTERABLE PARTICULATE MATTER^a

	Filt	Filterable Particulate		
Process	kg/Mg Feldspar Dried	lb/Ton Feldspar Dried	EMISSION FACTOR RATING	
Dryer with scrubber and demister ^b (SCC 3-05-034-02)	0.60	1.2	D	
Dryer with mechanical collector and scrubber ^{c,d} (SCC 3-05-034-02)	0.041	0.081	D	

^a SCC = Source Classification Code

^b Reference 4.

^c Reference 3.

^d Reference 5.

Table 11.27-2 (Metric And English Units). EMISSION FACTOR FOR CARBON DIOXIDE^a

	Carbon Dioxide			
Process	kg/Mg Feldspar Dried	lb/Ton Feldspar Dried	EMISSION FACTOR RATING	
Dryer with multiclone and scrubber ^b (SCC 3-05-034-02)	51	102	D	

^a SCC = Source Classification Code.

^b Scrubbers may achieve incidental control of CO₂ emissions. Multiclones do not control CO₂ emissions.

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11.28 Vermiculite Processing

11.28.1 Process Description¹⁻⁹

Vermiculite is the geological name given to a group of hydrated laminar minerals that are aluminum-iron-magnesium silicates and that resemble mica in appearance. The chemical formula for vermiculite is $(Mg,Ca,K,Fe^{+2})_3(Si,Al,Fe^{+3})_4O_{10}(OH)_2 \cdot 4H_2O$. When subjected to heat, vermiculite has the unusual property of exfoliating, or expanding, due to the interlaminar generation of steam. Uses of unexpanded vermiculite include muds for oil-well drilling and fillers in fire-resistant wallboard. The six-digit source classification code (SCC) for vermiculite processing is 3-05-033.

Vermiculite ore is mined using open-pit methods. Beneficiation includes screening, flotation, drying in rotary or fluid bed dryers, and expansion by exposure to high heat. All mined vermiculite is dried and sized at the mine site prior to exfoliation.

Crude Ore Processing -

Figure 11.28-1 is a process flow diagram for vermiculite processing. Crude ore from openpit mines is brought to the mill by truck and is loaded onto outdoor stockpiles. Primary processing consists of screening the raw material to remove the waste rock greater than 1.6 centimeters (cm) (5/8 inch [in.]) and returning the raw ore to stockpiles. Blending is accomplished as material is removed from stockpiles and conveyed to the mill feed bin. The blended ore is fed to the mill, where it is separated into fractions by wet screening and then concentrated by gravity. All concentrates are collected, dewatered, and dried in either a fluidized bed or rotary dryer. Drying reduces the moisture content of the vermiculite concentrate from approximately 15 to 20 percent to approximately 2 to 6 percent. At least one facility uses a hammermill to crush the material exiting the dryer. However, at most facilities, the dryer products are transported by bucket elevators to vibrating screens, where the material is classified. The dryer exhaust generally is ducted to a cyclone for recovering the finer grades of vermiculite concentrate. The classified concentrate then is stored in bins or silos for later shipment or exfoliation.

The rotary dryer is the more common dryer type used in the industry, although fluidized bed dryers also are used. Drying temperatures are 120° to 480°C (250° to 900°F), and fuel oil is the most commonly used fuel. Natural gas and propane also are used to fuel dryers.

Exfoliation -

After being transported to the exfoliation plant, the vermiculite concentrate is stored. The ore concentrate then is conveyed by bucket elevator or other means and is dropped continuously through a gas- or oil-fired vertical furnace. Exfoliation occurs after a residence time of less than 8 seconds in the furnace, and immediate removal of the expanded material from the furnace prevents damage to the structure of the vermiculite particle. Flame temperatures of more than 540°C (1000°F) are used for exfoliation. Proper exfoliation requires both a high rate of heat transfer and a rapid generation of steam within the vermiculite particles. The expanded product falls through the furnace and is air conveyed to a classifier system, which collects the vermiculite product and removes excessive fines. The furnace exhaust generally is ducted through a product recovery cyclone, followed by an emission control device. At some facilities, the exfoliated material is ground in a pulverizer prior to being classified. Finally, the material is packaged and stored for shipment.



Figure 11.28-1. Process flow diagram for vermiculite processing. (Source Classification Codes in parentheses.)

EMISSION FACTORS

11.28.2 Emissions And Controls^{1,4-11}

The primary pollutants of concern in vermiculite processing are particulate matter (PM) and PM less than 10 micrometers (PM-10). Particulate matter is emitted from screening, drying, exfoliating, and materials handling and transfer operations. Emissions from dryers and exfoliating furnaces, in addition to filterable and condensible PM and PM-10, include products of combustion, such as carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), and sulfur oxides (SO_x).

Wet scrubbers are typically used to control dryer emissions. The majority of expansion furnaces are ducted to fabric filters for emission control. However, wet scrubbers also are used to control the furnace emissions. Cyclones and fabric filters also are used to control emissions from screening, milling, and materials handling and transfer operations.

Table 11.28-1 summarizes the emission factors for vermiculite processing.

Table 11.28-1 EMISSION FACTORS FOR VERMICULITE PROCESSING^a

	Filterable PM ^b	Condensible organic PM ^c	Total PM ^d	CO ₂
Process	kg/Mg	kg/Mg	kg/Mg	kg/Mg
Rotary dryer, with wet collector (SCC 3-05-033-21,-22)	0.29°	ND	ND	50 ^f
Concentrate screening, with cyclone (SCC 3-05-033-36)	0.30 ^g	NA	0.30 ^g	NA
Concentrate conveyor transfer, with cyclone (SCC 3-05-033-41)	0.013 ^g	NA	0.013 ^g	NA
Exfoliation - gas-fired vertical furnace, with fabric filter (SCC 3-05-033-51)	0.32 ^h	0.18 ^j	0.50 ^k	ND
Product grinding, with fabric filter (SCC 3-05-033-61)	0.18 ^m	NA	0.18 ^m	NA

EMISSION FACTOR RATING: D

- ^a Factors represent uncontrolled emissions unless noted. Emission factor units for drying are kg/Mg of material feed; emission factor units for other processes are kg/Mg of product. 1 kg/Mg is equivalent to 1 lb/1,000 lb. SCC = Source Classification Code. ND = no data. NA = not applicable.
- applicable. ^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.
- ^c Condensible PM is that PM collected in the impinger portion of a PM sampling train. Condensible organic PM is the organic fraction of the condensible PM.
- ^d Total PM equals the sum of the filterable PM, condensible organic PM, and condensible inorganic PM.
- ^e Reference 8. EMISSION FACTOR RATING: E.
- ^f References 8,11. Factor represents uncontrolled emissions of CO₂.
- ^g Reference 11. For dried ore concentrate.
- ^h Reference 10.
- ^j Reference 10. Emissions may be largely from volatilization of oil used in ore beneficiation.
- ^k Sum of factors for filterable PM and condensible organic PM; does not include condensible inorganic PM.
- ^m Reference 9.

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11.29 Alumina Manufacturing

[Work In Progress]

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11.30 Perlite Processing

11.30.1 Process Description^{1,2}

Perlite is a glassy volcanic rock with a pearl-like luster. It usually exhibits numerous concentric cracks that cause it to resemble an onion skin. A typical perlite sample is composed of 71 to 75 percent silicon dioxide, 12.5 to 18.0 percent alumina, 4 to 5 percent potassium oxide, 1 to 4 percent sodium and calcium oxides, and trace amounts of metal oxides.

Crude perlite ore is mined, crushed, dried in a rotary dryer, ground, screened, and shipped to expansion plants. Horizontal rotary or vertical stationary expansion furnaces are used to expand the processed perlite ore.

The normal size of crude perlite expanded for use in plaster aggregates ranges from plus 250 micrometers (μ m) (60 mesh) to minus 1.4 millimeters (mm) (12 mesh). Crude perlite expanded for use as a concrete aggregate ranges from 1 mm (plus 16 mesh) to 0.2 mm (plus 100 mesh). Ninety percent of the crude perlite ore expanded for horticultural uses is greater than 841 μ m (20 mesh).

Crude perlite is mined using open-pit methods and then is moved to the plant site where it is stockpiled. Figure 11.30-1 is a flow diagram of crude ore processing. The first processing step is to reduce the diameter of the ore to approximately 1.6 centimeters (cm) (0.6 inch [in.]) in a primary jaw crusher. The crude ore is then passed through a rotary dryer, which reduces the moisture content from between 4 and 10 percent to less than 1 percent.

After drying, secondary grinding takes place in a closed-circuit system using screens, air classifiers, hammer mills, and rod mills. Oversized material produced from the secondary circuit is returned to the primary crusher. Large quantities of fines, produced throughout the processing stages, are removed by air classification at designated stages. The desired size processed perlite ore is stored until it is shipped to an expansion plant.

At the expansion plants, the processed ore is either preheated or fed directly to the furnace. Preheating the material to approximately 430 °C (800 °F) reduces the amount of fines produced in the expansion process, which increases usable output and controls the uniformity of product density. In the furnace, the perlite ore reaches a temperature of 760 to 980 °C (1400 to 1800 °F), at which point it begins to soften to a plastic state where the entrapped combined water is released as steam. This causes the hot perlite particles to expand 4 to 20 times their original size. A suction fan draws the expanded particles out of the furnace and transports them pneumatically to a cyclone classifier system to be collected. The air-suspended perlite particles are also cooled as they are transported to the collection equipment. The cyclone classifier system collects the expanded perlite, removes the excessive fines, and discharges gases to a baghouse or wet scrubber for air pollution control.

The grades of expanded perlite produced can also be adjusted by changing the heating cycle, altering the cutoff points for size collection, and blending various crude ore sizes. All processed products are graded for specific uses and are usually stored before being shipped. Most production rates are less than 1.8 megagrams per hour (Mg/hr) (2 tons/hr), and expansion furnace temperatures range from 870 to 980°C (1600 to 1800°F). Natural gas is typically used for fuel, although No. 2 fuel oil and propane are occasionally used. Fuel consumption varies from 2,800 to 8,960 kilojoules per kilogram (kJ/kg) (2.4 x 10^6 to 7.7 x 10^6 British thermal units per ton [Btu/ton]) of product.





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11.30.2 Emissions And Controls^{1,3-11}

The major pollutant of concern emitted from perlite processing facilities is particulate matter (PM). The dryers, expansion furnaces, and handling operations can all be sources of PM emissions. Emissions of nitrogen oxides from perlite expansion and drying generally are negligible. When sulfur-containing fuels are used, sulfur dioxide (SO₂) emissions may result from combustion sources. However, the most common type of fuel used in perlite expansion furnaces and dryers is natural gas, which is not a significant source of SO₂ emissions.

Test data from one perlite plant indicate that perlite expansion furnaces emit a number of trace elements including aluminum, calcium, chromium, fluorine, iron, lead, magnesium, manganese, mercury, nickel, titanium, and zinc. However, because the data consist of a single test run, emission factors were not developed for these elements. The sample also was analyzed for beryllium, uranium, and vanadium, but these elements were not detected.

To control PM emissions from both dryers and expansion furnaces, the majority of perlite plants use baghouses, some use cyclones either alone or in conjunction with baghouses, and a few use scrubbers. Frequently, PM emissions from material handling processes and from the dryers are controlled by the same device. Large plants generally have separate fabric filters for dryer emissions, whereas small plants often use a common fabric filter to control emissions from dryers and materials handling operations. In most plants, fabric filters are preceded by cyclones for product recovery. Wet scrubbers are also used in a small number of perlite plants to control emissions from perlite milling and expansion sources.

Table 11.30-1 presents emission factors for filterable PM and CO_2 emissions from the expanding and drying processes.

Table 11.30-1 (Metric And English Units). EMISSION FACTORS FOR PERLITE PROCESSING^a

	Filterable PM ^b		C	D ₂
	kg/Mg	lb/ton	kg/Mg	lb/ton
	Perlite	Perlite	Perlite	Perlite
Process	Expanded	Expanded	Expanded	Expanded
Expansion furnace (SCC 3-05-018-01)	ND	ND	420 ^c	850 ^c
Expansion furnace with wet cyclone (SCC 3-05-018-01)	1.1 ^d	2.1 ^d	NA	NA .
Expansion furnace with cyclone and baghouse (SCC 3-05-018-01)	0.15 ^e	0.29 ^e	NA	NA
Dryer (SCC 3-05-018)	ND	ND	16 ^f	31 ^f
Dryer with baghouse (SCC 3-05-018)	0.64 ^f	1.3 ^f	NA	NA
Dryer with cyclones and baghouses (SCC 3-05-018)	0.13 ^g	0.25 ^g	NA	NA

EMISSION FACTOR RATING: D

^a All emission factors represent controlled emissions. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

- ^c Reference 4.
- ^d Reference 11.
- ^e References 4,8.
- ^f Reference 10.
- ^g References 7,9.

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11.31 Abrasives Manufacturing

11.31.1 General¹

The abrasives industry is composed of approximately 400 companies engaged in the following separate types of manufacturing: abrasive grain manufacturing, bonded abrasive product manufacturing, and coated abrasive product manufacturing. Abrasive grain manufacturers produce materials for use by the other abrasives manufacturers to make abrasive products. Bonded abrasives manufacturing is very diversified and includes the production of grinding stones and wheels, cutoff saws for masonry and metals, and other products. Coated abrasive products manufacturers include those facilities that produce large rolls of abrasive-coated fabric or paper, known as jumbo rolls, and those facilities that manufacture belts and other products from jumbo rolls for end use.

The six-digit Source Classification Codes (SCC) for the industry are 3-05-035 for abrasive grain processing, 3-05-036 for bonded abrasives manufacturing, and 3-05-037 for coated abrasives manufacturing.

11.31.2 Process Description¹⁻⁷

The process description is broken into three distinct segments discussed in the following sections: production of the abrasive grains, production of bonded abrasive products, and production of coated abrasive products.

Abrasive Grain Manufacturing -

The most commonly used abrasive materials are aluminum oxides and silicon carbide. These synthetic materials account for as much as 80 to 90 percent of the total quantity of abrasive grains produced domestically. Other materials used for abrasive grains are cubic boron nitride (CBN), synthetic diamonds, and several naturally occurring minerals such as garnet and emery. The use of garnet as an abrasive grain is decreasing. Cubic boron nitride is used for machining the hardest steels to precise forms and finishes. The largest application of synthetic diamonds has been in wheels for grinding carbides and ceramics. Natural diamonds are used primarily in diamond-tipped drill bits and saw blades for cutting or shaping rock, concrete, grinding wheels, glass, quartz, gems, and high-speed tool steels. Other naturally occurring abrasive materials (including garnet, emery, silica sand, and quartz) are used in finishing wood, leather, rubber, plastics, glass, and softer metals.

The following paragraphs describe the production of aluminum oxide, silicon carbide, CBN, and synthetic diamond.

1. <u>Silicon carbide</u>. Silicon carbide (SiC) is manufactured in a resistance arc furnace charged with a mixture of approximately 60 percent silica sand and 40 percent finely ground petroleum coke. A small amount of sawdust is added to the mix to increase its porosity so that the carbon monoxide gas formed during the process can escape freely. Common salt is added to the mix to promote the carbon-silicon reaction and to remove impurities in the sand and coke. During the heating period, the furnace core reaches approximately 2200° C (4000° F), at which point a large portion of the load crystallizes. At the end of the run, the furnace contains a core of loosely knit silicon carbide crystals surrounded by unreacted or partially reacted raw materials. The silicon carbide crystals are removed to begin processing into abrasive grains.

2. <u>Aluminum oxide</u>. Fused aluminum oxide (Al_2O_3) is produced in pot-type, electric-arc furnaces with capacities of several tons. Before processing, bauxite, the crude raw material, is calcined at about 950°C (1740°F) to remove both free and combined water. The bauxite is then mixed with ground coke (about 3 percent) and iron borings (about 2 percent). An electric current is applied and the intense heat, on the order of 2000°C (3700°F), melts the bauxite and reduces the impurities that settle to the bottom of the furnace. As the fusion process continues, more bauxite mixture is added until the furnace is full. The furnace is then emptied and the outer impure layer is stripped off. The core of aluminum oxide is then removed to be processed into abrasive grains.

3. <u>Cubic boron nitride</u>. Cubic boron nitride is synthesized in crystal form from hexagonal boron nitride, which is composed of atoms of boron and nitrogen. The hexagonal boron nitride is combined with a catalyst such as metallic lithium at temperatures in the range of 1650 °C (3000°F) and pressures of up to 6,895,000 kilopascals (kPa) (1,000,000 pounds per square inch [psi]).

4. <u>Synthetic diamond</u>. Synthetic diamond is manufactured by subjecting graphite in the presence of a metal catalyst to pressures in the range of 5,571,000 to 13,100,000 kPa (808,000 to 1,900,000 psi) at temperatures in the range of 1400 to 2500° C (2500 to 4500° F).

Abrasive Grain Processing -

Abrasive grains for both bonded and coated abrasive products are made by graded crushing and close sizing of either natural or synthetic abrasives. Raw abrasive materials first are crushed by primary crushers and are then reduced by jaw crushers to manageable size, approximately 19 millimeters (mm) (0.75 inches [in]). Final crushing is usually accomplished with roll crushers that break up the small pieces into a usable range of sizes. The crushed abrasive grains are then separated into specific grade sizes by passing them over a series of screens. If necessary, the grains are washed in classifiers to remove slimes, dried, and passed through magnetic separators to remove iron-bearing material, before the grains are again closely sized on screens. This careful sizing is necessary to prevent contamination of grades by coarser grains. Sizes finer than 0.10 millimeter (mm) (250 grit) are separated by hydraulic flotation and sedimentation or by air classification. Figure 11.31-1 presents a process flow diagram for abrasive grain processing.

Bonded Abrasive Products Manufacturing -

The grains in bonded abrasive products are held together by one of six types of bonds: vitrified or ceramic (which account for more than 50 percent of all grinding wheels), resinoid (synthetic resin), rubber, shellac, silicate of soda, or oxychloride of magnesium. Figure 11.31-2 presents a process flow diagram for the manufacturing of vitrified bonded abrasive products.

Measured amounts of prepared abrasive grains are moistened and mixed with porosity media and bond material. Porosity media are used for creating voids in the finished wheels and consist of filler materials, such as paradichlorobenzene (moth ball crystals) or walnut shells, that are vaporized during firing. Feldspar and clays generally are used as bond materials in vitrified wheels. The mix is moistened with water or another temporary binder to make the wheel stick together after it is pressed. The mix is then packed and uniformly distributed into a steel grinding wheel mold, and compressed in a hydraulic press under pressures varying from 1,030 to 69,000 kPa (150 to 10,000 psi). If there is a pore-inducing media in the mix such as paradichlorobenzene, it is removed in a steam autoclave. Prior to firing, smaller wheels are dried in continuous dryers; larger wheels are dried in humidity-controlled, intermittent dry houses.

Most vitrified wheels are fired in continuous tunnel kilns in which the molded wheels ride through the kiln on a moving belt. However, large wheels are often fired in bell or periodic kilns. In the firing process, the wheels are brought slowly to temperatures approaching $1400^{\circ}C$ (2500°F)

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EMISSION FACTORS



Figure 11.31-1. Process flow diagram for abrasive grain processing. (Source Classification Codes in parentheses.)

Mineral Products Industry



Figure 11.31-2. Process flow diagram for the manufacturing of vitrified bonded abrasive products. (Source Classification Codes in parentheses.)

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for as long as several days depending on the size of the grinding wheels and the charge. This slow temperature ramp fuses the clay bond mixture so that each grain is surrounded by a hard glass-like bond that has high strength and rigidity. The wheels are then removed from the kiln and slowly cooled.

After cooling, the wheels are checked for distortion, shape, and size. The wheels are then machined to final size, balanced, and overspeed tested to ensure operational safety. Occasionally wax and oil, rosin, or sulfur are applied to improve the cutting effectiveness of the wheel.

Resin-bonded wheels are produced similarly to vitrified wheels. A thermosetting synthetic resin, in liquid or powder form, is mixed with the abrasive grain and a plasticizer (catalyst) to allow the mixture to be molded. The mixture is then hydraulically pressed to size and cured at 150 to 200° C (300 to 400° F) for a period of from 12 hours to 4 or 5 days depending on the size of the wheel. During the curing period, the mold first softens and then hardens as the oven reaches curing temperature. After cooling, the mold retains its cured hardness. The remainder of the production process is similar to that for vitrified wheels.

Rubber-bonded wheels are produced by selecting the abrasive grain, sieving it, and kneading the grain into a natural or synthetic rubber. Sulfur is added as a vulcanizing agent and then the mix is rolled between steel calendar rolls to form a sheet of the required thickness. The grinding wheels are cut out of the rolled sheet to a specified diameter and hole size. Scraps are kneaded, rolled, and cut out again. Then the wheels are vulcanized in molds under pressure in ovens at approximately 150 to 175°C (300 to 350°F). The finishing and inspection processes are similar to those for other types of wheels.

Shellac-bonded wheels represent a small percentage of the bonded abrasives market. The production of these wheels begins by mixing abrasive grain with shellac in a steam-heated mixer, which thoroughly coats the grain with the bond material (shellac). Wheels 3 mm (0.125 in.) thick or less are molded to exact size in heated steel molds. Thicker wheels are hot-pressed in steel molds. After pressing, the wheels are set in quartz sand and baked for a few hours at approximately $150^{\circ}C$ (300°F). The finishing and inspection processes are similar to those for other types of wheels.

In addition to grinding wheels, bonded abrasives are formed into blocks, bricks, and sticks for sharpening and polishing stones such as oil stones, scythe stones, razor and cylinder hones. Curved abrasive blocks and abrasive segments are manufactured for grinding or polishing curved surfaces. Abrasive segments can also be combined into large wheels such as pulpstones. Rubber pencil and ink erasers contain abrasive grains; similar soft rubber wheels, sticks, and other forms are made for finishing soft metals.

Coated Abrasive Products Manufacturing -

Coated abrasives consist of sized abrasive grains held by a film of adhesive to a flexible backing. The backing may be film, cloth, paper, vulcanized fiber, or a combination of these materials. Various types of resins, glues, and varnishes are used as adhesives or bonds. The glue is typically animal hide glue. The resins and varnishes are generally liquid phenolics or ureas, but depending on the end use of the abrasive, they may be modified to yield shorter or longer drying times, greater strength, more flexibility, or other required properties. Figure 11.31-3 presents a process flow diagram for the manufacturing of coated abrasive products.

The production of coated abrasive products begins with a length of backing, which is passed through a printing press that imprints the brand name, manufacturer, abrasive, grade number, and other identifications on the back. Jumbo rolls typically are 1.3 m (52 in.) wide by 1,372 m



Figure 11.31-3. Process flow diagram for the manufacturing of coated abrasive products. (Source Classification Codes in parentheses.)

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EMISSION FACTORS

(1,500 yards [yd]) to 2,744 m (3,000 yd) in length. The shorter lengths are used for fiber-backed products, and the longer lengths are used for film-backed abrasives. Then the backing receives the first application of adhesive bond, the "make" coat, in a carefully regulated film, varying in concentration and quantity according to the particle size of the abrasive to be bonded. Next, the selected abrasive grains are applied either by a mechanical or an electrostatic method. Virtually all of the abrasive grain used for coated abrasive products is either silicon carbide or aluminum oxide, augmented by small quantities of natural garnet or emery for woodworking, and minute amounts of diamond or CBN.

In mechanical application, the abrasive grains are poured in a controlled stream onto the adhesive-impregnated backing, or the impregnated backing is passed through a tray of abrasive thereby picking up the grains. In the electrostatic method, the adhesive-impregnated backing is passed adhesive-coated side down over a tray of abrasive grains, while at the same time passing an electric current through the abrasive. The electrostatic charge induced by the current causes the grains to imbed upright in the wet bond on the backing. In effect the sharp cutting edges of the grain are bonded perpendicular to the backing. It also causes the individual grains to be spaced more evenly due to individual grain repulsion. The amount of abrasive grains deposited on the backing can be controlled extremely accurately by adjusting the abrasive stream and manipulating the speed of the backing sheet through the abrasive.

After the abrasive is applied, the product is carried by a festoon conveyor system through a drying chamber to the sizing unit, where a second layer of adhesive, called the size coat or sand size, is applied. The size coat unites with the make coat to anchor the abrasive grains securely. The coated material is then carried by another longer festoon conveyor through the final drying and curing chamber in which the temperature and humidity are closely controlled to ensure uniform drying and curing. When the bond is properly dried and cured, the coated abrasive is wound into jumbo rolls and stored for subsequent conversion into marketable forms of coated abrasives. Finished coated abrasives are available as sheets, rolls, belts, discs, bands, cones, and many other specialized forms.

11.31.3 Emissions And Controls^{1,7}

Little information is available on emissions from the manufacturing of abrasive grains and products. However, based on similar processes in other industries, some assumptions can be made about the types of emissions that are likely to result from abrasives manufacturing.

Emissions from the production of synthetic abrasive grains, such as aluminum oxide and silicon carbide, are likely to consist primarily of particulate matter (PM), PM less than 10 micrometers (PM-10), and carbon monoxide (CO) from the furnaces. The PM and PM-10 emissions are likely to consist of filterable, inorganic condensable, and organic condensable PM. The addition of salt and sawdust to the furnace charge for silicon carbide production is likely to result in emissions of chlorides and volatile organic compounds (VOC). Aluminum oxide processing takes place in an electric arc furnace and involves temperatures up to $2600^{\circ}C$ ($4710^{\circ}F$) with raw materials of bauxite ore, silica, coke, iron borings, and a variety of minerals that include chromium oxide, cryolite, pyrite, and silane. This processing is likely to emit fluorides, sulfides, and metal constituents of the feed material. In addition, nitrogen oxides (NO_x) are emitted from the Solgel method of producing aluminum oxide.

The primary emissions from abrasive grain processing consist of PM and PM-10 from the crushing, screening, classifying, and drying operations. Particulate matter also is emitted from materials handling and transfer operations. Table 11.31-1 presents emission factors for filterable PM and CO_2 emissions from grain drying operations in metric and English units. Table 11.31-2

Table 11.31-1 (Metric And English Units). EMISSION FACTORS FOR ABRASIVE MANUFACTURING^a

EMISSION FACTOR RATING: E

	Filtera	ble PM ^b	CO ₂	
Process	kg/Mg	lb/ton ·	kg/Mg	lb/ton
Rotary dryer, sand blasting grit, with wet scrubber (SCC 3-05-035-05)	ND	ND	22°	43°
Rotary dryer, sand blasting grit, with fabric filter (SCC 3-05-035-05)	0.0073 ^d	0.015 ^d	ND	ND

^a Emission factors in kg/Mg and lb/ton of grit fed into dryer. SCC = Source Classification Code. ND = no data.

^b Filterable PM is that PM collected on or prior to the filter of an EPA Method 5 (or equivalent) sampling train.

^c Reference 9.

^d Reference 8.

Table 11.31-2 (Metric And English Units). EMISSION FACTORS FOR ABRASIVE MANUFACTURING^a

		Emission Factor		
Source	Pollutant	kg/Mg	lb/ton	
Rotary dryer: sand blasting grit, with wet scrubber (SCC 3-05-035-05)	Antimony	4.0 x 10 ⁻⁵	8.1 x 10 ⁻⁵	
	Arsenic	0.00012	0.00024	
	Beryllium	4.1 x 10 ⁻⁶	8.2 x 10 ⁻⁶	
	Lead	0.0022	0.0044	
	Cadmium	0.00048	0.00096	
	Chromium	0.00023	0.00045	
	Manganese	3.1 x 10 ⁻⁵	6.1 x 10 ⁻⁵	
	Mercury	8.5 x 10 ⁻⁷	1.7 x 10 ⁻⁶	
	Thallium	4.0 x 10 ⁻⁵	8.1 x 10 ⁻⁵	
	Nickel	0.0013	0.0026	

EMISSION FACTOR RATING: E

^a Reference 9. Emission factors in kg/Mg and lb/ton of grit fed into dryer. SCC = Source Classification Code.

presents emission factors developed from the results of a metals analysis conducted on a rotary dryer controlled by a wet scrubber.

Emissions generated in the production of bonded abrasive products may involve a small amount of dust generated by handling the loose abrasive, but careful control of sizes of abrasive particles limits the amount of fine particulate that can be entrained in the ambient air. However, for products made from finer grit sizes--less than 0.13 mm (200 grit)--PM emissions may be a significant problem. The main emissions from production of grinding wheels are generated during the curing of the bond structure for wheels. Heating ovens or kilns emit various types of VOC depending upon the composition of the bond system. Emissions from dryers and kilns also include products of combustion, such as CO, carbon dioxide (CO₂), nitrogen oxides (NO_x), and sulfur oxides (SO_x), in addition to filterable and condensable PM. Vitrified products produce some emissions as filler materials included to provide voids in the wheel structure are vaporized. Curing resins or rubber that is used in some types of bond systems also produce emissions of VOC. Another small source of emissions may be vaporization during curing of portions of the chloride- and sulfur-based materials that are included within the bonding structure as grinding aids.

Emissions that may result from the production of coated abrasive products consist primarily of VOC from the curing of the resin bonds and adhesives used to coat and attach the abrasive grains to the fabric or paper backing. Emissions from dryers and curing ovens also may include products of combustion, such as CO, CO_2 , NO_x , and SO_x , in addition to filterable and condensable PM. Emissions that come from conversion of large rolls of coated abrasives into smaller products such as sanding belts consist of PM and PM-10. In addition, some VOC may be emitted as a result of the volatilization of adhesives used to form joints in those products.

Fabric filters preceded by cyclones are used at some facilities to control PM emissions from abrasive grain production. This configuration of control devices can attain controlled emission concentrations of 37 micrograms per dry standard cubic meter (0.02 grains per dry standard cubic foot) and control efficiencies in excess of 99.9 percent. Little other information is available on the types of controls used by the abrasives industry to control PM emissions. However, it is assumed that other conventional devices such as scrubbers and electrostatic precipitators can be used to control PM emissions from abrasives grain and products manufacturing.

Scrubbers are used at some facilities to control NO_x emissions from aluminum oxide production. In addition, thermal oxidizers are often used in the coated abrasives industry to control emissions of VOC.

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12. METALLURGICAL INDUSTRY

The metallurgical industry can be broadly divided into primary and secondary metal production operations. Primary refers to the production of metal from ore. Secondary refers to production of alloys from ingots and to recovery of metal from scrap and salvage.

The primary metals industry includes both ferrous and nonferrous operations. These processes are characterized by emission of large quantities of sulfur oxides and particulate. Secondary metallurgical processes are also discussed, and the major air contaminant from such activity is particulate in the forms of metallic fumes, smoke, and dust.

12.1 Primary Aluminum Production

12.1.1 General¹

Primary aluminum refers to aluminum produced directly from mined ore. The ore is refined and electrolytically reduced to elemental aluminum. There are 13 companies operating 23 primary aluminum reduction facilities in the U. S. In 1991, these facilities produced 4.1 million megagrams (Mg) (4.5 million tons) of primary aluminum.

12.1.2 Process Description²⁻³

Primary aluminum production begins with the mining of bauxite ore, a hydrated oxide of aluminum consisting of 30 to 56 percent alumina (Al_2O_3) and lesser amounts of iron, silicon, and titanium. The ore is refined into alumina by the Bayer process. The alumina is then shipped to a primary aluminum plant for electrolytic reduction to aluminum. The refining and reducing processes are seldom accomplished at the same facility. A schematic diagram of primary aluminum production is shown in Figure 12.1-1.

12.1.2.1 Bayer Process Description -

In the Bayer process, crude bauxite ore is dried, ground in ball mills, and mixed with a preheated spent leaching solution of sodium hydroxide (NaOH). Lime (CaO) is added to control phosphorus content and to improve the solubility of alumina. The resulting slurry is combined with sodium hydroxide and pumped into a pressurized digester operated at 105 to 290°C (221 to 554°F). After approximately 5 hours, the slurry of sodium aluminate (NaAl₂OH) solution and insoluble red mud is cooled to 100°C (212°F) and sent through either a gravity separator or a wet cyclone to remove coarse sand particles. A flocculent, such as starch, is added to increase the settling rate of the red mud. The overflow from the settling tank contains the alumina in solution, which is further clarified by filtration and then cooled. As the solution cools, it becomes supersaturated with sodium aluminate. Fine crystals of alumina trihydrate (Al₂O₃ • 3H₂O) are seeded in the solution, causing the alumina to precipitate out as alumina trihydrate. After being washed and filtered, the alumina trihydrate is calcined to produce a crystalline form of alumina, which is advantageous for electrolysis.

12.1.2.2 Hall-Heroult Process -

Crystalline Al_2O_3 is used in the Hall-Heroult process to produce aluminum metal. Electrolytic reduction of alumina occurs in shallow rectangular cells, or "pots", which are steel shells lined with carbon. Carbon electrodes extending into the pot serve as the anodes, and the carbon lining as the cathode. Molten cryolite (Na₃AlF₆) functions as both the electrolyte and the solvent for the alumina. The electrolytic reduction of Al_2O_3 by the carbon from the electrode occurs as follows:

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2 \tag{1}$$

Aluminum is deposited at the cathode, where it remains as molten metal below the surface of the cryolite bath. The carbon anodes are continuously depleted by the reaction. The aluminum product is tapped every 24 to 48 hours beneath the cryolite cover, using a vacuum siphon. The aluminum is then transferred to a reverberatory holding furnace where it is alloyed, fluxed, and degassed to remove trace impurities. (Aluminum reverberatory furnace operations are discussed in detail in Section 12.8, "Secondary Aluminum Operations".) From the holding furnace, the aluminum is cast or transported to fabricating plants.

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Three types of aluminum reduction cells are now in use: prebaked anode cell (PB), horizontal stud Soderberg anode cell (HSS), and vertical stud Soderberg anode cell (VSS). Most of the aluminum produced in the U. S. is processed using the prebaked cells.

All three aluminum cell configurations require a "paste" (petroleum coke mixed with a pitch binder). Paste preparation includes crushing, grinding, and screening of coke and blending with a pitch binder in a steam jacketed mixer. For Soderberg anodes, the thick paste mixture is added directly to the anode casings. In contrast, the prebaked ("green") anodes are produced as an ancillary operation at a reduction plant.

In prebake anode preparation, the paste mixture is molded into green anode blocks ("butts") that are baked in either a direct-fired ring furnace or a Reid Hammer furnace, which is indirectly heated. After baking, steel rods are inserted and sealed with molten iron. These rods become the electrical connections to the prebaked carbon anode. Prebaked cells are preferred over Soderberg cells because they are electrically more efficient and emit fewer organic compounds.

12.1.3 Emissions And Controls^{2-9,12}

Controlled and uncontrolled emission factors for total particulate matter, gaseous fluoride, and particulate fluoride are given in Tables 12.1-1 and 12.1-2. Tables 12.1-3 and 12.1-4 give available data for size-specific particulate matter emissions for primary aluminum industry processes.

In bauxite grinding, hydrated aluminum oxide calcining, and materials handling operations, various dry dust collection devices (centrifugal collectors, multiple cyclones, or ESPs and/or wet scrubbers) have been used. Large amounts of particulate are generated during the calcining of hydrated aluminum oxide, but the economic value of this dust leads to the use of extensive controls which reduce emissions to relatively small quantities.

Emissions from aluminum reduction processes are primarily gaseous hydrogen fluoride and particulate fluorides, alumina, carbon monoxide, volatile organics, and sulfur dioxide (SO_2) from the reduction cells. The source of fluoride emissions from reduction cells is the fluoride electrolyte, which contains cryolite, aluminum fluoride (AIF_3) , and fluorospar (CaF_2) .

Particulate emissions from reduction cells include alumina and carbon from anode dusting, and cryolite, aluminum fluoride, calcium fluoride, chiolite $(Na_5Al_3F_{14})$, and ferric oxide. Representative size distributions for fugitive emissions from PB and HSS plants, and for particulate emissions from HSS cells, are presented in Tables 12.1-3 and 12.1-4.

Emissions from reduction cells also include hydrocarbons or organics, carbon monoxide, and sulfur oxides. These emission factors are not presented here because of a lack of data. Small amounts of hydrocarbons are released by PB pots, and larger amounts are emitted from HSS and VSS pots. In vertical cells, these organics are incinerated in integral gas burners. Sulfur oxides originate from sulfur in the anode coke and pitch, and concentrations of sulfur oxides in VSS cell emissions range from 200 to 300 parts per million. Emissions from PB plants usually have SO_2 concentrations ranging from 20 to 30 parts per million.

Emissions from anode bake ovens include the products of fuel combustion; high boiling organics from the cracking, distillation, and oxidation of paste binder pitch; sulfur dioxide from the sulfur in carbon paste, primarily from the petroleum coke; fluorides from recycled anode butts; and

Table 12.1-1 (Metric Units).EMISSION FACTORS FOR PRIMARY ALUMINUM
PRODUCTION PROCESSES^{a,b}

Operation	Total Particulate ^c	Gaseous Fluoride	Particulate Fluoride	References
Bauxite grinding ^d (SCC 3-03-000-01)				
Uncontrolled Spray tower Floating bed scrubber Quench tower and spray screen	3.0 0.9 0.85 0.5	Neg Neg Neg Neg	Neg Neg Neg Neg	1,3 1,3 1,3 1,3
Aluminum hydroxide calcining ^e (SCC 3-03-002-01)				
Uncontrolled ^f Spray tower Floating bed scrubber Quench tower ESP	100.0 30.0 28.0 17.0 2.0	Neg Neg Neg Neg Neg	Neg Neg Neg Neg Neg	1,3 1,3 1,3 1,3 1,3 1,3
Anode baking furnace (SCC 3-03-001-05)				
Uncontrolled Fugitive (SCC 3-03-001-11) Spray tower ESP Dry alumina scrubber	1.5 ND 0.375 0.375 0.03	0.45 ND 0.02 0.02 0.004	0.05 ND 0.015 0.015 0.001	2,10-11 ND 10 2 2,10
Prebake cell (SCC 3-03-001-01)				
Uncontrolled Fugitive (SCC 3-03-001-08) Emissions to collector Crossflow packed bed Multiple cyclones Spray tower Dry ESP plus spray tower Floating bed scrubber	47.0 2.5 44.5 13.15 9.8 8.9 2.25 8.9	12.0 0.6 11.4 3.25 11.4 0.7 0.7 0.25	10.0 0.5 9.5 2.8 2.1 1.9 1.7 1.9	1-2,10-11 2,10 2 10 2 2 2 2,10 2
Dry alumina scrubber Coated bag filter dry scrubber Dry plus secondary scrubber	0.9 0.9 0.35	0.1 1.7 0.2	0.2 0.2 0.15	2,10 2 10

EMISSION FACTOR RATING: A

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Operation	Total Particulate ^c	Gaseous Fluoride	Particulate Fluoride	References
Vertical Soderberg stud cell				
(SCC 3-03-001-03)				
Uncontrolled	39.0	16.5	5.5	2,10
Fugitive (SCC 3-03-001-10)	6.0	2.45	0.85	10
Emissions to collector	33.0	14.05	4.65	10
Multiple cyclones	16.5	14.05	2.35	2
Spray tower	8.25	0.15	1.15	2
Venturi scrubber	1.3	0.15	0.2	2
Dry alumina scrubber	0.65	Ò.15	0.1	2
Scrubber plus ESP plus spray				
screen and scrubber	3.85	0.75	0.65	2
Horizontal Soderberg stud cell				
(SCC 3-03-001-02)				
Uncontrolled	49.0	11.0	6.0	2,10
Fugitive (SCC 30300109)	5.0	1.1	0.6	2,10
Emissions to collector	44.0	9.9	5.4	2,10
Spray tower	11.0	3.75	1.35	2,10
Floating bed scrubber	9.7	0.2	1.2	2
Scrubber plus wet ESP	0.9	0.1	0.1	2,10
Wet ESP	0.9	0.5	0.1	10
Dry alumina scrubber	0.9	0.2	0.1	10

Table 12.1-1 (cont.).

^a Units are kilograms (kg) of pollutant/Mg of molten aluminum produced. SCC = Source Classification Code.

^b Sulfur oxides may be estimated, with an EMISSION FACTOR RATING of C, by the following calculations.

Anode baking furnace, uncontrolled SO₂ emissions (excluding furnace fuel combustion emissions): 20(C)(S)(1-0.01 K) kg/Mg (Metric units)

40(C)(S)(1-0.01 K) pounds/ton (lb/ton) (English units)

Prebake (reduction) cell, uncontrolled SO₂ emissions:

0.2(C)(S)(K) kg/Mg(Metric units)

0.4(C)(S)(K) lb/ton (English units)

where:

- = Anode consumption^{*} during electrolysis, lb anode consumed/lb С Al produced (English units)
- S = % sulfur in anode before baking
- K = % of total SO₂ emitted by prebake (reduction) cells.

*Anode consumption weight is weight of anode paste (coke + pitch) before baking.

^c Includes particulate fluorides, but does not include condensable organic particulate.

^d For bauxite grinding, units are kg of pollutant/Mg of bauxite processed.

^e For aluminum hydroxide calcining, units are kg of pollutant/Mg of alumina produced.

^f After multicyclones.

Table 12.1-2 (English Units).EMISSION FACTORS FOR PRIMARY ALUMINUM
PRODUCTION PROCESSES^{a,b}

Operation	Total Particulate ^c	Gaseous Fluoride	Particulate Fluoride	Reference
Bauxite grinding ^d (SCC 3-03-000-01)				
Uncontrolled Spray tower Floating bed scrubber Quench tower and spray screen	6.0 1.8 1.7 1.0	Neg Neg Neg Neg	Neg Neg Neg Neg	1,3 1,3 1,3 1,3
Aluminum hydroxide calcining ^e (SCC 3-03-002-01)				ŕ
Uncontrolled ^f Spray tower Floating bed scrubber Quench tower ESP	200.0 60.0 56.0 34.0 4.0	Neg Neg Neg Neg Neg	Neg Neg Neg Neg Neg	1,3 1,3 1,3 1,3 1,3 1,3
Anode baking furnace (SCC 3-03-001-05)				
Uncontrolled Fugitive (SCC 3-03-001-11) Spray tower ESP Dry alumina scrubber	3.0 ND 0.75 0.75 0.06	0.9 ND 0.04 0.04 0.009	0.1 ND 0.03 0.03 0.002	2,10-11 ND 10 2 2,10
Prebake cell (SCC 3-03-001-01)				
Uncontrolled Fugitive (SCC 3-03-001-08) Emissions to collector Multiple cyclones Dry alumina scrubber Dry ESP plus spray tower Spray tower Floating bed scrubber Coated bag filter dry scrubber	94.0 5.0 89.0 19.6 1.8 4.5 112.8 112.8 112.8 1.8 26.2	24.0 1.2 22.8 22.8 0.2 1.4 1.4 0.5 3.4	20.0 1.0 19.0 4.2 0.4 3.4 3.8 3.8 0.4 5.6	1-2,10-11 2,10 2 2,10 2,10 2 2 2 2 2
Crossflow packed bed Dry plus secondary scrubber	26.3 0.7	6.7 0.4	5.6 0.3	10 10

EMISSION FACTOR RATING: A

Operation	Total Particulate ^c	Gaseous Fluoride	Particulate Fluoride	Reference
Vertical Soderberg stud cell		~		
(SCC 3-03-001-03)				
Uncontrolled	78.0	33.0	11.0	2,10
Fugitive (SCC 3-03-001-10)	12.0	4.9	1.7	10
Emissions to collector	66.0	28.1	9.3	10
Spray tower	16.5	0.3	2.3	2
Venturi scrubber	2.6	0.3	0.4	2
Multiple cyclones	33.0	28.1	4.7	2
Dry alumina scrubber	1.3	0.3	0.2	2
Scrubber plus ESP plus spray				
screen and scrubber	7.7	1.5	1.3	2
Horizontal Soderberg stud cell				
(SCC 3-03-001-02)				
Uncontrolled	98.0	22.0	12.0	2,10
Fugitive (SCC 3-03-001-09)	10.0	2.2	1.2	2,10
Emissions to collector	88.0	19.8	10.8	2,10
Spray tower	22.0	7.5	2.7	2,10
Floating bed scrubber	19.4	0.4	2.4	2
Scrubber plus wet ESP	1.8	0.2	0.2	2,10
Wet ESP	1.8	1.0	0.2	10
Dry alumina scrubber	1.8	0.4	0.2	10

Table 12.1-2 (cont.).

^a Units are lb of pollutant/ton of molten aluminum produced. SCC = Source Classification Code.

^b Sulfur oxides may be estimated, with an EMISSION FACTOR RATING of C, by the following calculations.

Anode baking furnace, uncontrolled SO_2 emissions (excluding furnace fuel combustion emissions):

20(C)(S)(1-0.01 K) kg/Mg (Metric units) 40(C)(S)(1-0.01 K) lb/ton (English units)

Prebake (reduction) cell, uncontrolled SO₂ emissions:

$$0.2(C)(S)(K) \text{ kg/Mg}$$
 (Metric units)

0.4(C)(S)(K) lb/ton (English units)

where:

- C = Anode consumption^{*} during electrolysis, lb anode consumed/lb Al produced
- S = % sulfur in anode before baking
- K = % of total SO₂ emitted by prebake (reduction) cells.

*Anode consumption weight is weight of anode paste (coke + pitch) before baking.

^c Includes particulate fluorides, but does not include condensable organic particulate.

^d For bauxite grinding, units are lb of pollutant/ton of bauxite processed.

^e For aluminum hydroxide calcining, units are lb of pollutant/ton of alumina produced.

^f After multicyclones.
Table 12.1-3 (Metric Units). UNCONTROLLED EMISSION FACTORS AND PARTICLE SIZE DISTRIBUTION IN ALUMINUM PRODUCTION^a

	Prebake Aluminum Cells ^c		HSS Alum	inum Cells	HSS Redu	ction Cells
Particle Size ^b (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factor	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factor	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factor
0.625	13	0.33	8	0.40	26	12.7
1.25	18	0.46	13	0.65	32	15.7
2.5	28	0.70	17	0.85	40	19.6
5	43	1.08	23	1.15	50	25.5
10	58	1.45	31	1.55	58	28.4
15	65	1.62	39	1.95	63	30.9
Total	100	2.5	100	5.0	100	49

EMISSION FACTOR RATING: D (except as noted)

^a Reference 5. Units are kg of pollutant/Mg of aluminum produced.
^b Expressed as equivalent aerodynamic particle diameter.
^c EMISSION FACTOR RATING: C

Table 12.1-4 (English Units).UNCONTROLLED EMISSION FACTORS AND PARTICLE SIZE
DISTRIBUTION IN ALUMINUM PRODUCTION^a

EMISSION FACTOR RATING: D (except as noted)

	Prebake Aluminum Cells ^c		HSS Alum	inum Cells	HSS Reduc	ction Cells
Particle Size ^b (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factor	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factor	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factor
0.625	13	0.67	8	0.8	26	25.5
1.25	18	0.92	13	1.3	32	31.4
2.5	28	1.40	17	1.7	40	39.2
5	43	2.15	23	2.3	50	49.0
10	58	2.90	31	3.1	58	56.8
15	65	3.23	39	3.9	63	61.7
Total	100	2.5	100	10.0	100	98

^a Reference 5. Units are lb of pollutant/ton of aluminum produced.
 ^b Expressed as equivalent aerodynamic particle diameter.
 ^c EMISSION FACTOR RATING: C

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other particulate matter. Emission factors for these components are not included in this document due to insufficient data. Concentrations of uncontrolled SO_2 emissions from anode baking furnaces range from 5 to 47 parts per million (based on 3 percent sulfur in coke).

High molecular weight organics and other emissions from the anode paste are released from HSS and VSS cells. These emissions can be ducted to gas burners to be oxidized, or they can be collected and recycled or sold. If the heavy tars are not properly collected, they can cause plugging of exhaust ducts, fans, and emission control equipment.

A variety of control devices has been used to abate emissions from reduction cells and anode baking furnaces. To control gaseous and particulate fluorides and particulate emissions, 1 or more types of wet scrubbers (spray tower and chambers, quench towers, floating beds, packed beds, venturis) have been applied to all 3 types of reduction cells and to anode baking furnaces. In addition, particulate control methods such as wet and dry electrostatic precipitators (ESPs), multiple cyclones, and dry alumina scrubbers (fluid bed, injected, and coated filter types) are used on all 3 cell types and with anode baking furnaces.

The fluoride adsorption system is becoming more prevalent and is used on all 3 cell types. This system uses a fluidized bed of alumina, which has a high affinity for fluoride, to capture gaseous and particulate fluorides. The pot offgases are passed through the crystalline form of alumina, which was generated using the Bayer process. A fabric filter is operated downstream from the fluidized bed to capture the alumina dust entrained in the exhaust gases passing through the fluidized bed. Both the alumina used in the fluidized bed and that captured by the fabric filter are used as feedstock for the reduction cells, thus effectively recycling the fluorides. This system has an overall control efficiency of 99 percent for both gaseous and particulate fluorides. Wet ESPs approach adsorption in particulate removal efficiency, but they must be coupled to a wet scrubber or coated baghouse to catch hydrogen fluoride.

Scrubber systems also remove a portion of the SO_2 emissions. These emissions could be reduced by wet scrubbing or by reducing the quantity of sulfur in the anode coke and pitch, i. e., calcining the coke.

The molten aluminum may be batch treated in furnaces to remove oxide, gaseous impurities, and active metals such as sodium and magnesium. One process consists of adding a flux of chloride and fluoride salts and then bubbling chlorine gas, usually mixed with an inert gas, through the molten mixture. Chlorine reacts with the impurities to form HCl, Al_2O_3 , and metal chloride emissions. A dross forms on the molten aluminum and is removed before casting.

Potential sources of fugitive particulate emissions in the primary aluminum industry are bauxite grinding, materials handling, anode baking, and the 3 types of reduction cells (see Tables 12.1-1 and 12.1-2). These fugitive emissions probably have particulate size distributions similar to those presented in Tables 12.1-3 and 12.1-4.

References For Section 12.1

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12.2 Coke Production

12.2.1 General

Metallurgical coke is produced by destructive distillation of coal in coke ovens. Prepared coal is "coked", or heated in an oxygen-free atmosphere until all volatile components in the coal evaporate. The material remaining is called coke.

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Most metallurgical coke is used in iron and steel industry processes such as blast furnaces, sinter plants, and foundries to reduce iron ore to iron. Over 90 percent of the total metallurgical coke production is dedicated to blast furnace operations.

Most coke plants are co-located with iron and steel production facilities. Coke demand is dependent on the iron and steel industry. This represents a continuing decline from the about 40 plants that were operating in 1987.

12.2.2 Process Description^{1,2}

All metallurgical coke is produced using the "byproduct" method. Destructive distillation ("coking") of coal occurs in coke ovens without contact with air. Most U. S. coke plants use the Kopper-Becker byproduct oven. These ovens must remain airtight under the cyclic stress of expansion and contraction. Each oven has 3 main parts: coking chambers, heating chambers, and regenerative chambers. All of the chambers are lined with refractory (silica) brick. The coking chamber has ports in the top for charging of the coal.

A coke oven battery is a series of 10 to 100 coke ovens operated together. Figure 12.2-1 illustrates a byproduct coke oven battery. Each oven holds between 9 to 32 megagrams (Mg) (10 to 35 tons) of coal. Offtake flues on either end remove gases produced. Process heat comes from the combustion of gases between the coke chambers. Individual coke ovens operate intermittently, with run times of each oven coordinated to ensure a consistent flow of collectible gas. Approximately 40 percent of cleaned oven gas (after the removal of its byproducts) is used to heat the coke ovens. The rest is either used in other production processes related to steel production or sold. Coke oven gas is the most common fuel for underfiring coke ovens.

A typical coke manufacturing process is shown schematically in Figure 12.2-2. Coke manufacturing includes preparing, charging, and heating the coal; removing and cooling the coke product; and cooling, cleaning, and recycling the oven gas.

Coal is prepared for coking by pulverizing so that 80 to 90 percent passes through a 3.2 millimeter (1/8 inch) screen. Several types of coal may be blended to produce the desired properties, or to control the expansion of the coal mixture in the oven. Water or oil may be added to adjust the density of the coal to control expansion and prevent damage to the oven.

Coal may be added to the ovens in either a dry or wet state. Prepared wet coal is finely crushed before charging to the oven. Flash-dried coal may be transported directly to the ovens by the hot gases used for moisture removal. Wall temperatures should stay above 1100°C (2000°F) during loading operations and actual coking. The ports are closed after charging and sealed with luting ("mud") material.





Figure 12.2-2. Flow diagram of coke manufacturing. VOC = volatile organic compound. (Source Classification Codes in parentheses.)

The blended coal mass is heated for 12 to 20 hours for metallurgical coke. Thermal energy from the walls of the coke chamber heats the coal mass by conduction from the sides to the middle of the coke chamber. During the coking process, the charge is in direct contact with the heated wall surfaces and develops into an aggregate "plastic zone". As additional thermal energy is absorbed, the plastic zone thickens and merges toward the middle of the charge. Volatile gases escape in front of the developing zone due to heat progression from the side walls. The maximum temperature attained at the center of the coke mass is usually 1100 to 1150°C (2000 to 2100°F). This distills all volatile matter from the coal mass and forms a high-quality metallurgical coke.

After coking is completed (no volatiles remain), the coke in the chamber is ready to be removed. Doors on both sides of the chamber are opened and a ram is inserted into the chamber. The coke is pushed out of the oven in less than 1 minute, through the coke guide and into a quench car. After the coke is pushed from the oven, the doors are cleaned and repositioned. The oven is then ready to receive another charge of coal.

The quench car carrying the hot coke moves along the battery tracks to a quench tower where approximately 1130 liters (L) of water per Mg of coke (270 gallons of water per ton) are sprayed onto the coke mass to cool it from about 1100 to 80°C (2000 to 180°F) and to prevent it from igniting. The quench car may rely on a movable hood to collect particulate emissions, or it may have a scrubber car attached. The car then discharges the coke onto a wharf to drain and continue cooling. Gates on the wharf are opened to allow the coke to fall onto a conveyor that carries it to the crushing and screening station. After sizing, coke is sent to the blast furnace or to storage.

The primary purpose of modern coke ovens is the production of quality coke for the iron and steel industry. The recovery of coal chemicals is an economical necessity, as they equal approximately 35 percent of the value of the coal.

To produce quality metallurgical coke, a high-temperature carbonization process is used. High-temperature carbonization, which takes place above 900°C (1650°F), involves chemical conversion of coal into a mostly gaseous product. Gaseous products from high-temperature carbonization consist of hydrogen, methane, ethylene, carbon monoxide, carbon dioxide, hydrogen sulfide, ammonia, and nitrogen. Liquid products include water, tar, and crude light oil. The coking process produces approximately 338,000 L of coke oven gas (COG) per megagram of coal charged (10,800 standard cubic feet of COG per ton).

During the coking cycle, volatile matter driven from the coal mass passes upward through cast iron "goosenecks" into a common horizontal steel pipe (called the collecting main), which connects all the ovens in series. This unpurified "foul" gas contains water vapor, tar, light oils, solid particulate of coal dust, heavy hydrocarbons, and complex carbon compounds. The condensable materials are removed from the exhaust gas to obtain purified coke oven gas.

As it leaves the coke chamber, coke oven coal gas is initially cleaned with a weak ammonia spray, which condenses some tar and ammonia from the gas. This liquid condensate flows down the collecting main until it reaches a settling tank. Collected ammonia is used in the weak ammonia spray, while the rest is pumped to an ammonia still. Collected coal tar is pumped to a storage tank and sold to tar distillers, or used as fuel.

The remaining gas is cooled as it passes through a condenser and then compressed by an exhauster. Any remaining coal tar is removed by a tar extractor, either by impingement against a metal surface or collection by an electrostatic precipitator (ESP). The gas still contains 75 percent of original ammonia and 95 percent of the original light oils. Ammonia is removed by passing the gas

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through a saturator containing a 5 to 10 percent solution of sulfuric acid. In the saturator, ammonia reacts with sulfuric acid to form ammonium sulfate. Ammonium sulfate is then crystallized and removed. The gas is further cooled, resulting in the condensation of naphthalene. The light oils are removed in an absorption tower containing water mixed with "straw oil" (a heavy fraction of petroleum). Straw oil acts as an absorbent for the light oils, and is later heated to release the light oils for recovery and refinement. The last cleaning step is the removal of hydrogen sulfide from the gas. This is normally done in a scrubbing tower containing a solution of ethanolamine (Girbotol), although several other methods have been used in the past. The clean coke oven coal gas is used as fuel for the coke ovens, other plant combustion processes, or sold.

12.2.3 Emissions And Controls

Particulate, VOCs, carbon monoxide and other emissions originate from several byproduct coking operations: (1) coal preparation, (2) coal preheating (if used), (3) coal charging, (4) oven leakage during the coking period, (5) coke removal, (6) hot coke quenching and (7) underfire combustion stacks. Gaseous emissions collected from the ovens during the coking process are subjected to various operations for separating ammonia, coke oven gas, tar, phenol, light oils (benzene, toluene, xylene), and pyridine. These unit operations are potential sources of VOC emissions. Small emissions may occur when transferring coal between conveyors or from conveyors to bunkers. Figure 12.2-2 portrays major emission points from a typical coke oven battery.

The emission factors available for coking operations for total particulate, sulfur dioxide, carbon monoxide, VOCs, nitrogen oxides, and ammonia are given in Tables 12.2-1 and 12.2-2. Tables 12.2-3 and 12.2-4 give size-specific emission factors for coking operations.

A few domestic plants preheat the coal to about 260°C (500°F) before charging, using a flash drying column heated by the combustion of coke oven gas or by natural gas. The air stream that conveys coal through the drying column usually passes through conventional wet scrubbers for particulate removal before discharging to the atmosphere. Leaks occasionally occur from charge lids and oven doors during pipeline charging due to the positive pressure. Emissions from the other methods are similar to conventional wet charging.

Oven charging can produce significant emissions of particulate matter and VOCs from coal decomposition if not properly controlled. Charging techniques can draw most charging emissions into the battery collecting main. Effective control requires that goosenecks and the collecting main passages be cleaned frequently to prevent obstructions.

During the coking cycle. VOC emissions from the thermal distillation process can occur through poorly sealed doors, charge lids, offtake caps, collecting main, and cracks that may develop in oven brickwork. Door leaks may be controlled by diligent door cleaning and maintenance, rebuilding doors, and, in some plants, by manual application of lute (seal) material. Charge lid and offtake leaks may be controlled by an effective patching and luting program. Pushing coke into the quench car is another major source of particulate emissions. If the coke mass is not fully coked, VOCs and combustion products will be emitted. Most facilities control pushing emissions by using mobile scrubber cars with hoods, shed enclosures evacuated to a gas cleaning device, or traveling hoods with a fixed duct leading to a stationary gas cleaner.

Coke quenching entrains particulate from the coke mass. In addition, dissolved solids from the quench water may become entrained in the steam plume rising from the tower. Trace organic compounds may also be present.

EMISSION EMISSION EMISSION EMISSION EMISSION **EMISSION** FACTOR FACTOR FACTOR FACTOR FACTOR Ammonia^c FACTOR VOC^{c,d} NO_x^c Particulateb RATING RATING COc RATING RATING RATING RATING Type Of Operation SO2 Coal crushing (SCC 3-03-003-10) 0.055 D NA NA NA NA NA NA NA NA With cyclone NA NA Coal preheating (SCC 3-03-003-13) Uncontrollede 1.75 С ND NA ND NA ND NA ND NA ND NA With scrubber 0.125 С ND NA ND NA ND NA ND NA ND NA With wet ESP С ND ND NA ND NA ND 0.006 NA NA ND NA Oven charging^f (larry car) (SCC 3-03-003-02) 0.24 Ε 0.01 0.3 D 1.25 D 0.015 Uncontrolled D D 0.01 D With sequential charging Ε ND ND NA NA ND 0.008 NA ND NA ND NA Ε With scrubber 0.007 ND NA ND NA ND NA ND NA ND NA Oven door leaks (SCC 3-03-003-08) D D 0.3 D 0.75 D 0.005 Uncontrolled 0.27 D 0.03 D Oven pushing (SCC 3-03-003-03) Uncontrolled 0.58 В ND NA 0.035 D 0.1 D ND NA 0.05 D With ESP^g С ND 0.035 D 0.1 D ND NA NA 0.225 NA ND With venturi scrubberh D ND NA 0.035 D 0.1 D ND ND NA 0.09 NA With baghouse^h D 0.035 D ND 0.045 ND NA 0.1 D NA ND NA С D ND 0.035 0.1 D ND With mobile scrubber car^j 0.036 NA NA ND NA Quenching (SCC 3-03-003-04) Uncontrolled Dirty water^k 2.62 D NA NA ND NA ND NA NA NA ND NA Clean water^m 0.57 D NA NA ND NA ND NA NA NA ND NA With baffles B ND ND NA Dirty waterk 0.65 NA NA NA NA NA ND NA Clean water^m 0.27 В NA NA ND NA ND NA NA NA ND NA

Table 12.2-1 (Metric Units). EMISSION FACTORS FOR COKE MANUFACTURING^a

Table 12.2-1 (cont.).

		EMISSION		EMISSION		EMISSION		EMISSION		EMISSION		EMISSION
		FACTOR		FACTOR		FACTOR		FACTOR		FACTOR		FACTOR
Type Of Operation	Particulateb	RATING	so ₂	RATING	COc	RATING	VOC ^{c,d}	RATING	NO _x ^c	RATING	Ammonia ^c	RATING
Combustion stack	}											
(SCC 3-03-003-17, for COG)	}]]						ļ		
(SCC 3-03-003-16, for BFG)						1						
Uncontrolled (raw COG)	0.234	A	2.0 ⁿ	D	ND	NA	ND	NA	ND	NA	ND	NA
Uncontrolled (desulfurized COG)	0.234	A	0.14 ^p	C	ND	NA	ND	NA	ND	NA	ND	NA
Uncontrolled (BFG)	0.085	A	0.54 ^q	D	ND	NA	ND	NA	ND	NA	ND	NA
With ESP (BFG)	0.046	В	0.32 ^r	С	ND	NA	ND	NA	ND	NA	ND	NA
With ESP (COG)	0.055	D	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA
With baghouse (COG)										1		
	0.055	D	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA
Coke handling (SCC 3-03-003-12)												
With cyclone ⁸	0.003	D	ND	NA	ND	NA	NA	NA	NA	NA	NA	NA

^a Emission Factors are expressed in kg of pollutant/Mg of coke produced. SCC = Source Classification Code. NA = not applicable. ND = no data. BFG = blast furnace gas.

^b Reference 1.

^c Reference 23.

^d Expressed as methane.

^e Exhaust gas discharged from series of primary and secondary cyclones used to separate flash-dried coal from hot gas.

^f Charged coal has not been dried.

^g Emissions captured by coke side shed.

^h Emissions captured by travelling hood.
 ^j Emissions captured by quench car enclosure.

^k Dirty water \geq 5000 Mg/L total dissolved solids.

^m Clean water ≤ 1500 Mg/L total dissolved solids.

ⁿ Reference 4. Factor for SO₂ is based on these representative conditions: (1) sulfur content of coal charged to oven is 0.8 weight %; (2) about 33 weight % of total sulfur in coal charged to oven is transferred to coke oven gas; (3) about 40% of coke oven gas is burned during underfiring operation, and about 60% is used in other operations where the rest of the SO₂ (3 kilograms/megagrams [6 lb/ton] of coal charged) is discharged; (4) gas used in underfiring has not been desulfurized.

^p Reference 21, desulfurized COG.

^q Reference 22.

^r Reference 23.

^s Defined as crushing and screening.

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Table 12.2-2 (English Units). EMISSION FACTORS FOR COKE MANUFACTURING^a

		EMISSION		EMISSION		EMISSION		EMISSION		EMISSION		EMISSION
		FACTOR		FACTOR	•	FACTOR		FACTOR]	FACTOR		FACTOR
Type Of Operation	Particulateb	RATING	SO2	RATING	CO ^c	RATING	VOC ^{c,d}	RATING	NOx ^c	RATING	Ammonia ^c	RATING
$C_{0.01}$ contributes (SCC 3-03-003-10)												
With avalance	0.11	D	NIA	NA	NIA	NA		NA		NA	NIA	NA
with cyclone	0.11	U					NA			NA		NA
Coal preheating (SCC 3-03-003-13)												
Uncontrolled ^e	3.50	С	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA
With scrubber	0.25	С	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA
With wet ESP	0.012	с	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA
Oven charging ^f (larry car) (SCC 3-03-003-02)												
Uncontrolled	0.48	E	0.02	D	0.6	D	2.5	D	0.03	D	0.02	D
With sequential charging	0.016	E	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA
With scrubber	0.014	Е	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA
 Oven door leaks (SCC 3-03-003-08)												
Uncontrolled	0.54	D	ND	D	0.6	D	1.50	D	0.01	D	0.06	D
Oven pushing (SCC 3-03-003-03)												
Uncontrolled	1.15	В	ND	NA	0.07	D	0.2	D	ND	NA	0.1	D
With ESP ^g	0.45	с	ND	NA	0.07	D	0.2	D	ND	NA	ND	NA
With venturi scrubber ^h	0.18	D	ND	NA	0.07	D	0.2	D	ND	NA	ND	NA
With baghouse ^h	0.09	D	ND	NA	0.07	D	0.2	D	ND	NA	ND	NA
With mobile scrubber car	0.072	С	ND	NA	0.07	D	0.2	D	ND	NA	ND	NA
Quenching ^j (SCC 3-03-003-04)						-						
Uncontrolled		{	l	[[1	}
Dirty water ^k	5.24	D	NA	NA	ND	NA	ND	NA	NA	NA	ND	NA
Clean water ^m	1.13	D	NA	NA	ND	NA	ND	NA	NA	NA	ND	NA
With baffles												
Dirty water ^k	1.30	В	NA	NA	ND	NA	ND	NA	NA	NA	ND	NA
Clean water ^m	0.54	В	NA	NA	ND	NA	ND	NA	NA	NA	ND	NA

Table 12.2-2 (cont.).

		EMISSION FACTOR		EMISSION FACTOR		EMISSION FACTOR		EMISSION FACTOR		EMISSION FACTOR		EMISSION FACTOR
Type Of Operation	Particulateb	RATING	SO2	RATING	COc	RATING	VOC ^{c,d}	RATING	NO _x c	RATING	Ammonia ^c	RATING
Combustion stack												
(SCC 3-03-003-17, for COG)									I			[[
(SCC 3-03-003-18, for BFG)												
Uncontrolled (raw COG)	0.47	A	4.0 ⁿ	D	ND	NA	ND	NA	ND	NA	ND	NA
Uncontrolled (desulfurized COG)	0.47	A	0.28 ^p	С	ND	NA	ND	NA	ND	NA	ND	NA
Uncontrolled (BFG)	0.17	A	1.08 ^q	С	ND	NA	ND	NA	ND	NA	ND	NA
With ESP (BFG)	ND	В	0.64 ^r	С	ND	NA	ND	NA	ND	NA	ND	NA
With ESP (COG)	0.091	D	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA
With baghouse (COG)	0.11	D	ND	NA	ND	NA	ND	NA	ND	NA	ND	NA
Coke handling (SCC 3-03-003-12)]					1	
With cyclone ^s	0.006	D	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

^a Emission Factors are expressed in lb/ton of coke produced. SCC = Source Classification Code. NA = not applicable. ND = no data. BFG = blast furnace gas.

- ^b Reference 1.
- ^c References 23.
- ^d Expressed as methane.
- ^e Exhaust gas discharged from series of primary and secondary cyclones used to separate flash dried coal from hot gas.
- ^f Charged coal has not been dried.
- ^g Emissions captured by coke side shed. ^h Emissions captured by travelling hood.

- ^j Emissions captured by quench car enclosure. ^k Dirty water \geq 5000 mg/L total dissolved solids.
- ^m Clean water ≤ 1500 mg/L total dissolved solids.
- ⁿ Reference 4. Factor for SO₂ is based on these representative conditions: (1) sulfur content of coal charged to oven is 0.8 weight %; (2) about 33 weight % of total sulfur in coal charged to oven is transferred to coke oven gas; (3) about 40% of coke oven gas is burned during underfiring operation, and about 60% is used in other operations where the rest of the SO₂ (3 kilogram/megagram [6 pounds/ton] of coal charged) is discharged; (4) gas used in underfiring has not been desulfurized.
- ^p Reference 21, desulfurized COG.
- ^q Reference 22.
- ^r Reference 23.
- ^s Defined as crushing and screening.

12.2-9

Table 12.2-3. (Metric Units). SIZE-SPECIFIC EMISSION FACTORS FOR COKE MANUFACTURING^a

Process	Particle Size (µm) ^b	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factors	Reference Source Number
Coal preheating (SCC 3-03-003-13)	0.5	44	0.8	8
Uncontrolled	1.0	48.5	0.8	
	2.0	55	1.0	
	2.5	59.5	1.0	
	5.0	79.5	1.4	
	10.0	97.5	1.7	
	15.0	99.9	1.7	
		100	1.7	
Controlled with venturi scrubber	0.5	78	0.10	8
	1.0	80	0.10	
	2.0	83	0.10	
	2.5	84	0.11	
	5.0	88	0.11	
	10.0	94	0.12	
	15.0	96.5	0.12	
		100	0.12	
Oven charging sequential or stage ^c	0.5	13.5	0.001	9
	1.0	25.2	0.002	
	2.0	33.6	0.003	
	2.5	39.1	0.003	
	5.0	45.8	0.004	
	10.0	48.9	0.004	
	15.0	49.0	0.004	
		100	0.008	
Coke pushing (SCC 3-03-003-03)	0.5	3.1	0.02	10 - 15
Uncontrolled	1.0	7.7	0.04	
	2.0	14.8	0.09	
	2.5	16.7	0.10	
	5.0	26.6	0.15	
	10.0	43.3	0.25	
	15.0	50.0	0.29	
		100	0.58	

EMISSION FACTOR RATING: D (except as noted)

Table 12.2-3 (cont.).

Process	Particle Size (μm) ^b	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factors	Reference Source Number
Controlled with venturi scrubber	0.5	24	0.02	10, 12
	1.0	47	0.04	,
	2.0	66.5	0.06	
	2.5	73.5	0.07	
	5.0	75	0.07	
	10.0	87	0.08	
	15.0	92	0.08	
		100	0.09	
Mobile scrubber car	1.0	28.0	0.010	16
	2.0	29.5	0.011	
	2.5	30.0	0.011	
	5.0	30.0	0.011	
	10.0	32.0	0.012	
	15.0	35.0	0.013	
		100	0.036	
Quenching (SCC 3-03-003-04)				17
Uncontrolled (dirty water)	1.0	13.8	0.36	
	2.5	19.3	0.51	
	5.0	21.4	0.56	
	10.0	22.8	0.60	
	15.0	26.4	0.69	
		100	2.62	
Uncontrolled (clean water)	1.0	4.0	0.02	17
	2.5	11.1	0.06	
	5.0	19.1	0.11	
	10.0	30.1	0.17	
	15.0	37.4	0.21	
		100	0.57	
With baffles (dirty water)	1.0	8.5	0.06	17
	2.5	20.4	0.13	
	5.0	24.8	0.16	
	10.0	32.3	0.21	
	15.0	49.8	0.32	
		100	0.65	

Process	Particle Size (µm) ^b	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factors	Reference Source Number
With baffles (clean water)	1.0	1.2	0.003	17
	2.5	6.0	0.02	
	5.0	7.0	0.02	
	10.0	9.8	0.03	
	15.0	15.1	0.04	
		100	0.27	
Combustion stack ^d				
Uncontrolled	1.0	77.4	0.18	18 - 20
	2.0	85.7	0.20	
	2.5	93.5	0.22	
	5.0	95.8	0.22	
	10.0	95.9	0.22	
	15.0	96	0.22	
		100	0.23	

Table 12.2-3 (cont.).

a Emission factors are expressed in kg of pollutant/Mg of material processed.
 b μm = micrometers
 c EMISSION FACTOR RATING: E
 d Material processed is coke.

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Table 12.2-4. (English Units).SIZE-SPECIFIC EMISSION FACTORSFOR COKE MANUFACTURING^a

Process	Particle Size (µm) ^b	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factors	Reference Source Number
Coal preheating (SCC 3-03-003-13)	0.5	44	0.8	8
Uncontrolled	1.0	48.5	0.8	
	2.0	55	1.0	
	2.5	59.5	1.0	
	5.0	79.5	1.4	
	10.0	97.5	1.7	
	15.0	99.9	1.7	
		100	1.7	
Controlled with venturi scrubber	0.5	78	0.10	8
	1.0	80	0.10	
	2.0	83	0.10	
	2.5	84	0.11	
	5.0	88	0.11	
	10.0	94	0.12	
	15.0	96.5	0.12	
		100	0.12	
Oven charging sequential or stage ^c	0.5	13.5	0.001	9
	1.0	25.2	0.002	
	2.0	33.6	0.003	
	2.5	39.1	0.003	
	5.0	45.8	0.004	
	10.0	48.9	0.004	
	15.0	49.0	0.004	
		100	0.008	
Coke pushing (SCC 3-03-003-03)	0.5	3.1	0.02	10 - 15
Uncontrolled	1.0	7.7	0.04	
	2.0	14.8	0.09	
	2.5	16.7	0.10	
	5.0	26.6	0.15	
	10.0	43.3	0.25	
	15.0	50.0	0.29	
		100	0.58	

EMISSION FACTOR RATING: D (except as noted)

Table 12.2-4 (cont.).

Process	Particle Size (µm) ^b	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factors	Reference Source Number
Controlled with venturi scrubber	0.5	24	0.02	10, 12
	1.0	47	0.04	,
	2.0	66.5	0.06	
	2.5	73.5	0.07	
	5.0	75	0.07	
	10.0	87	0.08	
	15.0	92	0.08	
		100	0.09	
Mobile scrubber car	1.0	28.0	0.010	16
	2.0	29.5	0.011	
	2.5	30.0	0.011	
	5.0	30.0	0.011	
	10.0	32.0	0.012	
	15.0	35.0	0.013	
		100	0.036	
Quenching (SCC 3-03-003-04)				17
Uncontrolled (dirty water)	1.0	13.8	0.36	
	2.5	19.3	0.51	
	5.0	21.4	0.56	
	10.0	22.8	0.60	
	15.0	26.4	0.69	
		100	2.62	
Uncontrolled (clean water)	1.0	4.0	0.02	17
	2.5	11.1	0.06	
	5.0	19.1	0.11	
	10.0	30.1	0.17	
	15.0	37.4	0.21	
		100	0.57	
With baffles (dirty water)	1.0	8.5	0.06	17
	2.5	20.4	0.13	
	5.0	24.8	0.16	
	10.0	32.3	0.21	
	15.0	49.8	0.32	
		100	0.65	

Process	Particle Size (µm) ^b	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factors	Reference Source Number
With baffles (clean water)	1.0	1.2	0.003	17
	2.5	6.0	0.02	
	5.0	7.0	0.02	
	10.0	9.8	0.03	
	15.0	15.1	0.04	
		100	0.27	
Combustion stack ^d				
Uncontrolled	1.0	77.4	0.18	18 - 20
	2.0	85.7	0.20	
	2.5	93.5	0.22	
	5.0	95.8	0.22	
	10.0	95.9	0.22	
	15.0	96	0.22	
		100	0.23	

Table 12.2-4 (cont.).

^a Emission factors are expressed in lb of pollutant/ton of material processed.

^b μ m = micrometers.

^c EMISSION FACTOR RATING: E

^d Material processed is coke.

Combustion of gas in the battery flues produces emissions from the underfire or combustion stack. Sulfur dioxide emissions may also occur if the coke oven gas is not desulfurized. Coal fines may leak into the waste combustion gases if the oven wall brickwork is damaged. Conventional gas cleaning equipment, including electrostatic precipitators and fabric filters, have been installed on battery combustion stacks.

Fugitive particulate emissions are associated with material handling operations. These operations consist of unloading, storing, grinding and sizing of coal, screening, crushing, storing, and unloading of coke.

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12.3 Primary Copper Smelting

12.3.1 General¹

Copper ore is produced in 13 states. In 1989, Arizona produced 60 percent of the total U. S. ore. Fourteen domestic mines accounted for more than 95 percent of the 1.45 megagrams (Mg) (1.6 millon tons) of ore produced in 1991.

Copper is produced in the U. S. primarily by pyrometallurgical smelting methods. Pyrometallurgical techniques use heat to separate copper from copper sulfide ore concentrates. Process steps include mining, concentration, roasting, smelting, converting, and finally fire and electrolytic refining.

12.3.2 Process Description²⁻⁴

Mining produces ores with less than 1 percent copper. Concentration is accomplished at the mine sites by crushing, grinding, and flotation purification, resulting in ore with 15 to 35 percent copper. A continuous process called floatation, which uses water, various flotation chemicals, and compressed air, separates the ore into fractions. Depending upon the chemicals used, some minerals float to the surface and are removed in a foam of air bubbles, while others sink and are reprocessed. Pine oils, cresylic acid, and long-chain alcohols are used for the flotation of copper ores. The flotation concentrates are then dewatered by clarification and filtration, resulting in 10 to 15 percent water, 25 percent sulfur, 25 percent iron, and varying quantities of arsenic, antimony, bismuth, cadmium, lead, selenium, magnesium, aluminum, cobalt, tin, nickel, tellurium, silver, gold, and palladium.

A typical pyrometallurgical copper smelting process, as illustrated in Figure 12.3-1, includes 4 steps: roasting, smelting, concentrating, and fire refining. Ore concentration is roasted to reduce impurities, including sulfur, antimony, arsenic, and lead. The roasted product, calcine, serves as a dried and heated charge for the smelting furnace. Smelting of roasted (calcine feed) or unroasted (green feed) ore concentrate produces matte, a molten mixture of copper sulfide (Cu_2S), iron sulfide (FeS), and some heavy metals. Converting the matte yields a high-grade "blister" copper, with 98.5 to 99.5 percent copper. Typically, blister copper is then fire-refined in an anode furnace, cast into "anodes", and sent to an electrolytic refinery for further impurity elimination.

Roasting is performed in copper smelters prior to charging reverberatory furnaces. In roasting, charge material of copper concentrate mixed with a siliceous flux (often a low-grade copper ore) is heated in air to about 650 °C (1200 °F), eliminating 20 to 50 percent of the sulfur as sulfur dioxide (SO₂). Portions of impurities such as antimony, arsenic, and lead are driven off, and some iron is converted to iron oxide. Roasters are either multiple hearth or fluidized bed; multiple hearth roasters accept moist concentrate, whereas fluidized bed roasters are fed finely ground material. Both roaster types have self-generating energy by the exothermic oxidation of hydrogen sulfide, shown in the reaction below.

$$H_2S + O_2 \rightarrow SO_2 + H_2O + Thermal energy$$
 (1)

In the smelting process, either hot calcine from the roaster or raw unroasted concentrate is melted with siliceous flux in a smelting furnace to produce copper matte. The required heat comes from partial oxidation of the sulfide charge and from burning external fuel. Most of the iron and

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ORE CONCENTRATES WITH SILICA FLUXES



TO ELECTROLYTIC REFINERY

Figure 12.3-1. Typical primary copper smelter process. (Source Classification Codes in parentheses.)

EMISSION FACTORS

some of the impurities in the charge oxidize with the fluxes to form a slag on top of the molten bath, which is periodically removed and discarded. Copper matte remains in the furnace until tapped. Matte ranges from 35 to 65 percent copper, with 45 percent the most common. The copper content percentage is referred to as the matte grade. The 4 smelting furnace technologies used in the U. S. are reverberatory, electric, Noranda, and flash.

The reverberatory furnace smelting operation is a continuous process, with frequent charging and periodic tapping of matte, as well as skimming slag. Heat is supplied by natural gas, with conversion to oil during gas restrictions. Furnace temperature may exceed 1500°C (2730°F), with the heat being transmitted by radiation from the burner flame, furnace walls, and roof into the charge of roasted and unroasted materials mixed with flux. Stable copper sulfide (Cu₂S) and stable FeS form the matte with excess sulfur leaving as sulfur dioxide.

Electric arc furnace smelters generate heat with carbon electrodes that are lowered through the furnace roof and submerged in the slag layer of the molten bath. The feed consists of dried concentrates or calcine. The chemical and physical changes occurring in the molten bath are similar to those occurring in the molten bath of a reverberatory furnace. The matte and slag tapping practices are also similar.

The Noranda process, as originally designed, allowed the continuous production of blister copper in a single vessel by effectively combining roasting, smelting, and converting into 1 operation. Metallurgical problems, however, led to the operation of these reactors for the production of copper matte. The Noranda process uses heat generated by the exothermic oxidation of hydrogen sulfide. Additional heat is supplied by oil burners or by coal mixed with the ore concentrates. Figure 12.3-2 illustrates the Noranda process reactor.

Flash furnace smelting combines the operations of roasting and smelting to produce a highgrade copper matte from concentrates and flux. In flash smelting, dried ore concentrates and finely ground fluxes are injected together with oxygen and preheated air (or a mixture of both), into a furnace maintained at approximately 1000°C (1830°F). As with the Noranda process reactor, and in contrast to reverberatory and electric furnaces, flash furnaces use the heat generated from partial oxidation of their sulfide charge to provide much or all of the required heat.

Slag produced by flash furnace operations contains significantly higher amounts of copper than reverberatory or electric furnaces. Flash furnace slag is treated in a slag cleaning furnace with coke or iron sulfide. Because copper has a higher affinity for sulfur than oxygen, the copper in the slag (as copper oxide) is converted to copper sulfide. The copper sulfide is removed and the remaining slag is discarded.

Converting produces blister copper by eliminating the remaining iron and sulfur present in the matte. All but one U. S. smelter uses Pierce-Smith converters, which are refractory-lined cylindrical steel shells mounted on trunnions at either end, and rotated about the major axis for charging and pouring. An opening in the center of the converter functions as a mouth through which molten matte, siliceous flux, and scrap copper are charged and gaseous products are vented. Air, or oxygen-rich air, is blown through the molten matte. Iron sulfide is oxidized to form iron oxide (FeO) and SO₂. Blowing and slag skimming continue until an adequate amount of relatively pure Cu_2S , called "white metal", accumulates in the bottom of the converter. A final air blast ("final blow") oxidizes the copper sulfide to SO₂, and blister copper forms, containing 98 to 99 percent coppers. The blister copper is removed from the converter for subsequent refining. The SO₂ produced throughout the operation is vented to pollution control devices.



Figure 12.3-2. Schematic of the Noranda process reactor.

One domestic smelter uses Hoboken converters. The Hoboken converter, unlike the Pierce-Smith converter, is fitted with an inverted u-shaped side flue at one end to siphon gases from the interior of the converter directly to an offgas collection system. The siphon results in a slight vacuum at the converter mouth.

Impurities in blister copper may include gold, silver, antimony, arsenic, bismuth, iron, lead, nickel, selenium, sulfur, tellurium, and zinc. Fire refining and electrolytic refining are used to purify blister copper even further. In fire refining, blister copper is usually mixed with flux and charged into the furnace, which is maintained at 1100°C (2010°F). Air is blown through the molten mixture to oxidize the copper and any remaining impurities. The impurities are removed as slag. The remaining copper oxide is then subjected to a reducing atmosphere to form purer copper. The fire-refined copper is then cast into anodes for even further purification by electrolytic refining.

Electrolytic refining separates copper from impurities by electrolysis in a solution containing copper sulfate (Cu_2SO_4) and sulfuric acid (H_2SO_4). The copper anode is dissolved and deposited at the cathode. As the copper anode dissolves, metallic impurities precipitate and form a sludge. Cathode copper, 99.95 to 99.96 percent pure, is then cast into bars, ingots, or slabs.

12.3.3 Emissions And Controls

Emissions from primary copper smelters are principally particulate matter and sulfur oxides (SO_x) . Emissions are generated from the roasters, smelting furnaces, and converters. Fugitive emissions are generated during material handling operations.

Roasters, smelting furnaces, and converters are sources of both particulate matter and SO_x . Copper and iron oxides are the primary constituents of the particulate matter, but other oxides, such as arsenic, antimony, cadmium, lead, mercury, and zinc, may also be present, along with metallic sulfates and sulfuric acid mist. Fuel combustion products also contribute to the particulate emissions from multiple hearth roasters and reverberatory furnaces.

Gas effluent from roasters usually are sent to an electrostatic precipitator (ESP) or spray chamber/ESP system or are combined with smelter furnace gas effluent before particulate collection. Overall, the hot ESPs remove only 20 to 80 percent of the total particulate (condensed and vapor) present in the gas. Cold ESPs may remove more than 95 percent of the total particulate present in

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the gas. Particulate collection systems for smelting furnaces are similar to those for roasters. Reverberatory furnace off-gases are usually routed through waste heat boilers and low-velocity balloon flues to recover large particles and heat, then are routed through an ESP or spray chamber/ESP system.

In the standard Pierce-Smith converter, flue gases are captured during the blowing phase by the primary hood over the converter mouth. To prevent the hood from binding to the converter with splashing molten metal, a gap exists between the hood and the vessel. During charging and pouring operations, significant fugitives may be emitted when the hood is removed to allow crane access. Converter off-gases are treated in ESPs to remove particulate matter, and in sulfuric acid plants to remove SO_2 .

Remaining smelter operations process material containing very little sulfur, resulting in insignificant SO_2 emissions. Particulate may be emitted from fire refining operations. Electrolytic refining does not produce emissions unless the associated sulfuric acid tanks are open to the atmosphere. Crushing and grinding systems used in ore, flux, and slag processing also contribute to fugitive dust problems.

Control of SO₂ from smelters is commonly performed in a sulfuric acid plant. Use of a sulfuric acid plant to treat copper smelter effluent gas streams requires that particulate-free gas containing minimum SO₂ concentrations, usually of at least 3 percent SO₂, be maintained. Table 12.3-1 shows typical average SO₂ concentrations from the various smelter units. Additional information on the operation of sulfuric acid plants is discussed in Section 8.10 of this document. Sulfuric acid plants also treat converter gas effluent. Some multiple hearth and all fluidized bed roasters use sulfuric acid plants. Reverberatory furnace effluent contains minimal SO₂ and is usually released directly to the atmosphere with no SO₂ reduction. Effluent from the other types of smelter furnaces contain higher concentrations of SO₂ and are treated in sulfuric acid plants before being vented. Single-contact sulfuric acid plants achieve 92.5 to 98 percent conversion of plant effluent gas. Double-contact acid plants collect from 98 to more than 99 percent of the SO₂, emitting about 500 parts per million (ppm) SO₂. Absorption of the SO₂ in dimethylaniline (DMA) solution has also been used in domestic smelters to produce liquid SO₂.

Particular emissions vary depending upon configuration of the smelting equipment. Tables 12.3-2 and 12.3-3 give the emission factors for various smelter configurations, and Tables 12.3-4, 12.3-5, 12.3-6, 12.3-7, 12.3-8, and 12.3-9 give size-specific emission factors for those copper production processes where information is available.

Roasting, smelting, converting, fire refining, and slag cleaning are potential fugitive emission sources. Tables 12.3-10 and 12.3-11 present fugitive emission factors for these sources. Tables 12.3-12, 12.3-13, 12.3-14, 12.3-15, 12.3-16, and 12.3-17 present cumulative size-specific particulate emission factors for fugitive emissions from reverberatory furnace matte tapping, slag tapping, and converter slag and copper blow operations. The actual quantities of emissions from these sources depend on the type and condition of the equipment and on the smelter operating techniques.

Fugitive emissions are generated during the discharge and transfer of hot calcine from multiple hearth roasters. Fluid bed roasting is a closed loop operation, and has negligible fugitive emissions. Matte tapping and slag skimming operations are sources of fugitive emissions from smelting furnaces. Fugitive emissions can also result from charging of a smelting furnace or from leaks, depending upon the furnace type and condition.

Table 12.3-1. TYPICAL SULFUR DIOXIDE CONCENTRATIONS INOFFGAS FROM PRIMARY COPPER SMELTING SOURCES^a

Unit	SO ₂ Concentration (Volume %)			
Multiple hearth roaster (SCC 3-03-005-02)	1.5 - 3			
Fluidized bed roaster (SCC 3-03-005-09)	10 - 12			
Reverberatory furnace (SCC 3-03-005-03)	0.5 - 1.5			
Electric arc furnace (SCC 3-03-005-10)	4 - 8			
Flash smelting furnace (SCC 3-03-005-12)	10 - 70			
Continuous smelting furnace (SCC 3-03-005-36)	5 - 15			
Pierce-Smith converter (SCC 3-03-005-37)	4 - 7			
Hoboken converter (SCC 3-03-005-38)	8			
Single contact H ₂ SO ₄ plant (SCC 3-03-005-39)	0.2 - 0.26			
Double contact H ₂ SO ₄ plant (SCC 3-03-005-40)	0.05			

^a SCC = Source Classification Code.

Each of the various converter stages (charging, blowing, slag skimming, blister pouring, and holding) is a potential source of fugitive emissions. During blowing, the converter mouth is in the stack (a close-fitting primary hood is over the mouth to capture offgases). Fugitive emissions escape from the hood. During charging, skimming, and pouring, the converter mouth is out of the stack (the converter mouth is rolled out of its vertical position, and the primary hood is isolated). Fugitive emissions are discharged during roll out.

Table 12.3	2. (Metric	Units).	EMISSION	FACTORS	FOR	PRIMARY	COPPER	SMELTERS ^{a,t}	0
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Configuration ^c	Process	Particulate	EMISSION FACTOR RATING	Sulfur Dioxide ^d	EMISSION FACTOR RATING	References
Reverberatory furnace (RF) followed by converter (C) (SCC 3-03-005-23)	RF C	25 18	B B	160 370	B B	4-10 9,11-15
Multiple hearth roaster (MHR) followed by	MHR	22	B	140	B	4-5,16-17
reverberatory furnace (RF) and converter (C)	RF	25	B	90	B	4-9,18-19
(SCC 3-03-005-29)	C	18	B	300	B	8,11-13
Fluid bed roaster (FBR) followed by	FBR	ND	ND	180	B	20
reverberatory furnace (RF) and converter (C)	RF	25	B	90	B	e
(SCC 3-03-005-25)	C	18	B	270	B	e
Concentrate dryer (CD) followed by electric	CD	5	B	0.5	B	21-22
furnace (EF) and converter (C)	EF	50	B	120	B	15
(SCC 3-03-005-27)	C	18	B	410	B	8,11-13,15

Table	12.3-2	(cont.).
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Configuration ^c	Procęss	Particulate	EMISSION FACTOR RATING	Sulfur Dioxide ^d	EMISSION FACTOR RATING	References
Fluid bed roaster (FBR) followed by electric	FBR	ND	ND	180	В	20
furnace (EF) and converter (C)	EF	50	В	45	В	15,23
(SCC 3-03-005-30)	С	18	В	300	В	3
Concentrate dryer (CD) followed by flash	CD	5	В	0.5	В	21-22
furnace (FF), cleaning furnace (SS) and	FF	70	В	410	В	24
converter (C)	ssf	5	В	0.5	В	22
(SCC 3-03-005-26)	Ce	ND ^g	ND ^g	120	В	22
Concentrate dryer (CD) followed by Noranda	CD	5	В	0.5	В	21-22
reactors (NR) and converter (C)	NR	ND	ND	ND	ND	_
(SCC 3-03-005-41)	С	ND	ND	ND	ND	_

^a Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter. Approximately
 4 unit weights of concentrate are required to produce 1 unit weight of blister copper.
 SCC = Source Classification Code. ND = no data.

^b For particulate matter removal, gaseous effluents from roasters, smelting furnaces, and converters usually are treated in hot ESPs at 200 to 340°C (400 to 650°F) or in cold ESPs with gases cooled to about 120°C (250°F before) ESP. Particulate emissions from copper smelters contain volatile metallic oxides that remain in vapor form at higher temperatures, around 120°C (250°F). Therefore, overall particulate removal in hot ESPs may range 20 to 80% and in cold ESPs may be 99%. Converter gas effluents and, at some smelters, roaster gas effluents are treated in single contact acid plants (SCAP) or double contact acid plants (DCAP) for SO₂ removal. Typical SCAPs are about 96% efficient, and DCAPs are up to 99.8% efficient in SO₂ removal. They also remove over 99% of particulate matter. Noranda and flash furnace offgases are also processed through acid plants and are subject to the same collection efficiencies as cited for converters and some roasters.

- ^c In addition to sources indicated, each smelter configuration contains fire refining anode furnaces after the converters. Anode furnaces emit negligible SO₂. No particulate emission data are available for anode furnaces.
- ^d Factors for all configurations except reverberatory furnaces followed by converters have been developed by normalizing test data for several smelters to represent 30% sulfur content in concentrated ore.
- ^e Based on the test data for the configuration multiple hearth roaster followed by reverberatory furnaces and converters.
- ^f Used to recover copper from furnace slag and converter slag.
- ^g Since converters at flash furnace and Noranda furnace smelters treat high copper content matte, converter particulate emissions from flash furnace smelters are expected to be lower than those from conventional smelters with multiple hearth roasters, reverberatory furnaces, and converters.

Configuration ^c	Process	Particulate	EMISSION FACTOR RATING	Sulfu r dioxide ^d	EMISSION FACTOR RATING	References
Reverberatory furnace (RF) followed by converter (C) (SCC 3-03-005-23)	RF C	50 36	B B	320 740	B B	4-10 9,11-15
Multiple hearth roaster (MHR) followed by reverberatory furnace (RF) and converter (C) (SCC 3-03-005-29)	MHR RF C	45 50 36	B B B	280 180 600	B B B	4-5,16-17 4-9,18-19 8,11-13
Fluid bed roaster (FBR) followed by reverberatory furnace (RF) and converter (C) (SCC 3-03-005-25)	FBR RF C	ND 50 36	ND B B	360 180 540	B B B	20 ° °
Concentrate dryer (CD) followed by electric furnace (EF) and converter (C) (SCC 3-03-005-27)	CD EF C	10 100 36	B B B	1 240 820	B B B	21-22 15 8,11-13,15
Fluid bed roaster (FBR) followed by electric furnace (EF) and converter (C) (SCC 3-03-005-30)	FBR EF C	ND 100 36	ND B B	360 90 600	B B B	20 15,23 3
Concentrate dryer (CD) followed by flash furnace (FF), cleaning furnace (SS) and converter (C) (SCC 3-03-005-26)	CD FF SS ^f C°	10 140 10 ND ^g	B B B ND ^g	1 820 1 240	B B B B	21-22 24 22 22
Concentrate dryer (CD) followed by Noranda reactors (NR) and converter (C) (SCC 3-03-005-41)	CD NR C	10 ND ND	B ND ND	1 ND ND	B ND ND	21-22 — —

Table 12.3-3 (English Units). EMISSION FACTORS FOR PRIMARY COPPER SMELTERS^{a,b}

^a Expressed as lb of pollutant/ton of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of blister copper. SCC = Source Classification Code. ND = no data.

^b For particulate matter removal, gaseous effluents from roasters, smelting furnaces and converters usually are treated in hot ESPs at 200 to 340°C (400 to 650°F) or in cold ESPs with gases cooled to about 120°C (250°F before) ESP. Particulate emissions from copper smelters contain volatile metallic oxides which remain in vapor form at higher temperatures, around 120°C (250°F). Therefore, overall particulate removal in hot ESPs may range 20 to 80% and in cold ESPs may be 99%. Converter gas effluents and, at some smelters, roaster gas effluents are treated in single contact acid plants (SCAPs) or double contact acid plants (DCAPs) for SO₂ removal. Typical SCAPs are about 96% efficient, and DCAPs are up to 99.8% efficient in SO₂ removal. They also remove over 99% of particulate matter. Noranda and flash furnace offgases are also processed through acid plants and are subject to the same collection efficiencies as cited for converters and some roasters.

^c In addition to sources indicated, each smelter configuration contains fire refining anode furnaces after the converters. Anode furnaces emit negligible SO₂. No particulate emission data are available for anode furnaces.

Table 12.3-3 (cont.).

- ^d Factors for all configurations except reverberatory furnaces followed by converters have been developed by normalizing test data for several smelters to represent 30% sulfur content in concentrated ore.
- ^e Based on the test data for the configuration multiple hearth roaster followed by reverberatory furnaces and converters.
- ^f Used to recover copper from furnaces slag and converter slag.
- ^g Since converters at flash furnaces and Noranda furnace smelters treat high copper content matte, converter particulate emissions from flash furnace smelters are expected to be lower than those from conventional smelters with multiple hearth roasters, reverberatory furnaces, and converters.

Table 12.3-4 (Metric Units).PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSIONFACTORS FOR MULTIPLE HEARTH ROASTER AND REVERBERATORYSMELTER OPERATIONS^a

Particle Sizeb	Cumulative Emission Factors				
μm)	Uncontrolled	ESP Controlled ^c			
15	47	0.47			
10	47	0.47			
5	47	0.46			
2.5	46	0.40			
1.25	31	0.36			
0.625	12	0.29			

EMISSION FACTOR RATING: D

^a Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter.

^b Expressed as aerodynamic equivalent diameter.

^c Nominal particulate removal efficiency is 99%.

Table 12.3-5 (English Units). PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFIC EMISSION FACTORS FOR MULTIPLE HEARTH ROASTER AND REVERBERATORY SMELTER OPERATIONS^a

EMISSION FACTOR RATING: D

Particle Sizeb	Cumulative Emission Factors				
μm)	Uncontrolled	ESP Controlled ^c			
15	95	0.95			
10	94	0.94			
5	93	0.93			
2.5	80	0.80			
1.25	72	0.72			
0.625	59	0.59			

^a Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter.

^b Expressed as aerodynamic equivalent diameter.

^c Nominal particulate removal efficiency is 99%.

Table 12.3-6 (Metric Units).SIZE-SPECIFIC EMISSION FACTORSFOR REVERBERATORY SMELTER OPERATIONS^a

Particle Sizeb	Cumulative Emission Factors				
μm)	Uncontrolled	ESP Controlled ^c			
15	NR	0.21			
10	6.8	0.20			
5	5.8	0.18			
2.5	5.3	0.14			
1.25	4.0	0.10			
0.625	2.3	0.08			

EMISSION FACTOR RATING: E

^a Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter. NR = not reported because of excessive extrapolation.

^b Expressed as aerodynamic equivalent diameter.

^c Nominal particulate removal efficiency is 99%.

Table 12.3-7 (English Units). SIZE-SPECIFIC EMISSION FACTORS FOR REVERBERATORY SMELTER OPERATIONS^a

EMISSION FACTOR RATING: E

Darticle Sizeb	Cumulative Emission Factors			
μm)	Uncontrolled	ESP Controlled ^c		
15	NR	0.42		
10	13.6	0.40		
5	11.6	0.36		
2.5	10.6	0.28		
1.25	8.0	0.20		
0.625	4.6	0.16		

^a Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter.
 NR = not reported because of excessive extrapolation.

^b Expressed as aerodynamic equivalent diameter.

^c Nominal particulate removal efficiency is 99%.

Table 12.3-8 (Metric Units). SIZE-SPECIFIC EMISSION FACTORS FOR COPPER CONVERTER OPERATIONS^a

Particle Sizeb	Cumulative Emission Factors			
(μm)	Uncontrolled	ESP Controlled ^c		
15	NR	0.18		
10	10.6	0.17		
5	5.8	0.13		
2.5	2.2	0.10		
1.25	0.5	0.08		
0.625	0.2	0.05		

EMISSION FACTOR RATING: E

^a Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter. NR = not reported because of excessive extrapolation.

^b Expressed as aerodynamic equivalent diameter.

^c Nominal particulate removal efficiency is 99%.

Table 12.3-9 (English Units).SIZE-SPECIFIC EMISSION FACTORS FOR
REVERBERATORY SMELTER OPERATIONS^a

EMISSION FACTOR RATING: E

Darticle Sizeb	Cumulative Emission Factors			
raticle Size (μin)	Uncontrolled	ESP Controlled ^c		
15	NR	0.36		
10	21.2	0.36		
5	11.5	0.26		
2.5	4.3	0.20		
1.25	1.1	0.15		
0.625	0.4	0.11		

^a Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter.
 NR = not reported because of excessive extrapolation.

^b Expressed as aerodynamic equivalent diameter.

^c Nominal particulate removal efficiency is 99%.

Table 12.3-10 (Metric Units). FUGITIVE EMISSION FACTORS FOR PRIMARY COPPER SMELTERS^a

EMISSION FACTOR RATING: B

Source Of Emission	Particulate	SO ₂
Roaster calcine discharge (SCC 3-03-005-13)	1.3	0.5
Smelting furnace ^b (SCC 3-03-005-14)	0.2	2
Converter (SCC 3-03-005-15)	2.2	65
Converter slag return (SCC 3-03-005-18)	ND	0.05
Anode refining furnace (SCC 3-03-005-16)	0.25	0.05
Slag cleaning furnace ^c (SCC 3-03-005-17)	4	3

^a References 17,23,26-33. Expressed as mass kg of pollutant/Mg of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of copper metal. Factors for flash furnace smelters and Noranda furnace smelters may be lower than reported values. SCC = Source Classification Code. ND = no data.

^b Includes fugitive emissions from matte tapping and slag skimming operations. About 50% of fugitive particulate emissions and about 90% of total SO₂ emissions are from matte tapping operations, with remainder from slag skimming.

^c Used to treat slags from smelting furnaces and converters at the flash furnace smelter.

Table 12.3-11 (English Units). FUGITIVE EMISSION FACTORS FOR PRIMARY COPPER SMELTERS^a

Source Of Emission	Particulate	SO ₂
Roaster calcine discharge (SCC 3-03-005-13)	2.6	1
Smelting furnace ^b (SCC 3-03-005-14)	0.4	4
Converter (SCC 3-03-005-15)	4.4	130
Converter slag return (SCC 3-03-005-18)	ND	0.1
Anode refining furnace (SCC 3-03-005-16)	0.5	0.1
Slag cleaning furnace ^c (SCC 3-03-005-17)	8	6

EMISSION FACTOR RATING: B

^a References 17, 23, 26-33. Expressed as mass lb of pollutant/ton of concentrated ore processed by the smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weight of copper metal. Factors for flash furnace smelters and Noranda furnace smelters may be lower than reported values. SCC = Source Classification Code. ND = no data.

^b Includes fugitive emissions from matte tapping and slag skimming operations. About 50% of fugitive particulate emissions and about 90% of total SO₂ emissions are from matte tapping operations, with remainder from slag skimming.

^c Used to treat slags from smelting furnaces and converters at the flash furnace smelter.

Table 12.3-12 (Metric Units). UNCONTROLLED PARTICLE SIZE AND SIZE-SPECIFICEMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACEMATTE TAPPING OPERATIONS^a

Particle Size ^b (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	76	0.076
10	74	0.074
5	72	0.072
2.5	69	0.069
1.25	67	0.067
0.625	65	0.065

EMISSION FACTOR RATING: D

^a Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter. ^b Expressed as aerodynamic equivalent diameter.

Table 12.3-13 (English Units). UNCONTROLLED PARTICLE SIZE AND SIZE SPECIFICEMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACEMATTE TAPPING OPERATIONS^a

EMISSION FACTOR RATING: D

Particle Size ^b (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	76	0.152
10	74	0.148
5	72	0.144
2.5	69	0.138
1.25	67	0.134
0.625	65	0.130

^a Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter.

^b Expressed as aerodynamic equivalent diameter.

Table 12.3-14 (Metric Units). PARTICLE SIZE AND SIZE-SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACE SLAG TAPPING OPERATIONS^a

Particle Size ^b (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	33	0.033
10	28	0.028
5	25	0.025
2.5	22	0.022
1.25	20	0.020
0.625	17	0.017

EMISSION FACTOR RATING: D

^a Reference 26. Expressed as kg of pollutant/Mg of concentrated ore processed by the smelter. ^b Expressed as aerodynamic equivalent diameter.

Table 12.3-15 (English Units). PARTICLE SIZE AND SIZE-SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM REVERBERATORY FURNACE SLAG TAPPING OPERATIONS^a

EMISSION FACTOR	RATING: D
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Particle Size ^b (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	33	0.066
10	28	0.056
5	25	0.050
2.5	22	0.044
1.25	20	0.040
0.625	17	0.034

^a Reference 26. Expressed as lb of pollutant/ton of concentrated ore processed by the smelter. ^b Expressed as aerodynamic equivalent diameter.
Table 12.3-16 (Metric Units). PARTICLE SIZE AND SIZE-SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM CONVERTER SLAG AND COPPER BLOW OPERATIONS^a

Particle Size ^b (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	98	2.2
10	96	2.1
5	87	1.9
2.5	60	1.3
1.25	47	1.0
0.625	38	0.8

EMISSION FACTOR RATING: D

^a Reference 26. Expressed as kg of pollutant/Mg weight of concentrated ore processed by the smelter.

^b Expressed as aerodynamic equivalent diameter.

Table 12.3-17 (English Units). PARTICLE SIZE AND SIZE-SPECIFIC EMISSION FACTORS FOR FUGITIVE EMISSIONS FROM CONVERTER SLAG AND COPPER BLOW OPERATIONS^a

EMISSION FACTOR RATING: • D

Particle Size ^b (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Emission Factors
15	98	4.3
10	96	4.2
5	87	3.8
2.5	60	2.6
1.25	47	2.1
0.625	38	1.7

^a Reference 26. Expressed as lb of pollutant/ton weight of concentrated ore processed by the smelter. ^b Expressed as aerodynamic equivalent diameter.

Table 12.3-18 (Metric Units). LEAD EMISSION FACTORS FOR PRIMARY COPPER SMELTERS^a

Operation	EMISSION FACTOR ^b	EMISSION FACTOR RATING
Roasting ^c (SCC 3-03-005-02)	0.075	С
Smelting ^d (SCC 3-03-005-03)	0.036	С
Converting ^e (SCC 3-03-005-04)	0.13	С
Refining (SCC 3-03-005-05)	ND	ND

^a Reference 34. Expressed as kg of pollutant/Mg of concentrated ore processed by smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weights of copper metal. Based on test data for several smelters with 0.1 to 0.4% lead in feed throughput. SCC = Source Classification Code. ND = no data.

^b For process and fugitive emissions totals.

^c Based on test data on multihearth roasters. Includes total of process emissions and calcine transfer fugitive emissions. The latter are about 10% of total process and fugitive emissions.

^d Based on test data on reverberatory furnaces. Includes total process emissions and fugitive emissions from matte tapping and slag skimming operations. Fugitive emissions from matte tapping and slag skimming operations amount to about 35% and 2%, respectively.

^e Includes total of process and fugitive emissions. Fugitives constitute about 50% of total.

Operation	EMISSION FACTOR ^b	EMISSION FACTOR RATING
Roasting ^c (SCC 3-03-005-02)	0.15	С
Smelting ^d (SCC 3-03-005-03)	0.072	С
Converting ^e (SCC 3-03-005-04)	0.27	С
Refining (SCC 3-03-005-05)	ND	ND

Table 12.3-19 (English Units). LEAD EMISSION FACTORS FOR PRIMARY COPPER SMELTERS^a

^a Reference 34. Expressed as lb of pollutant/ton of concentrated ore processed by smelter. Approximately 4 unit weights of concentrate are required to produce 1 unit weights of copper metal. Based on test data for several smelters with 0.1 to 0.4% lead in feed throughput. SCC = Source Classification Code. ND = no data.

^b For process and fugitive emissions totals.

^c Based on test data on multihearth roasters. Includes total of process emissions and calcine transfer Fugitive emissions. The latter are about 10% of total process and fugitive emissions.

^d Based on test data on reverberatory furnaces. Includes total process emissions and fugitive emissions from matte tapping and slag skimming operations. Fugitive emissions from matte tapping and slag skimming operations amount to about 35% and 2%, respectively.

^e Includes total of process and fugitive emissions. Fugitives constitute about 50% of total.

Occasionally slag or blister copper may not be transferred immediately to the converters from the smelting furnace. This holding stage may occur for several reasons, including insufficient matte in the smelting furnace, unavailability of a crane, and others. Under these conditions, the converter is rolled out of its vertical position and remains in a holding position and fugitive emissions may result.

At primary copper smelters, both process emissions and fugitive particulate from various pieces of equipment contain oxides of many inorganic elements, including lead. The lead content of particulate emissions depends upon both the lead content of the smelter feed and the process offgas temperature. Lead emissions are effectively removed in particulate control systems operating at low temperatures, about $120^{\circ}C$ (250°F).

Tables 12.3-18 and 12.3-19 present process and fugitive lead emission factors for various operations of primary copper smelters.

Fugitive emissions from primary copper smelters are captured by applying either local ventilation or general ventilation techniques. Once captured, fugitive emissions may be vented directly to a collection device or can be combined with process off-gases before collection. Close-fitting exhaust hood capture systems are used for multiple hearth roasters and hood ventilation systems for smelt matte tapping and slag skimming operations. For converters, secondary hood systems or building evacuation systems are used.

A number of hazardous air pollutants (HAPs) are identified as being present in some copper concentrates being delivered to primary copper smelters for processing. They include arsenic, antimony, cadmium, lead, selenium, and cobalt. Specific emission factors are not presented due to lack of data. A part of the reason for roasting the concentrate is to remove certain volatile impurities including arsenic and antimony. There are HAPs still contained in blister copper, including arsenic, antimony, lead, and selenium. After electrolytic refining, copper is 99.95 percent to 99.97 percent pure.

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12.4 Ferroalloy Production

12.4.1 General

Ferroalloy is an alloy of iron with some element other than carbon. Ferroalloy is used to physically introduce or "carry" that element into molten metal, usually during steel manufacture. In practice, the term ferroalloy is used to include any alloys that introduce reactive elements or alloy systems, such as nickel and cobalt-based aluminum systems. Silicon metal is consumed in the aluminum industry as an alloying agent and in the chemical industry as a raw material in silicon-based chemical manufacturing.

The ferroalloy industry is associated with the iron and steel industries, its largest customers. Ferroalloys impart distinctive qualities to steel and cast iron and serve important functions during iron and steel production cycles. The principal ferroalloys are those of chromium, manganese, and silicon. Chromium provides corrosion resistance to stainless steels. Manganese is essential to counteract the harmful effects of sulfur in the production of virtually all steels and cast iron. Silicon is used primarily for deoxidation in steel and as an alloying agent in cast iron. Boron, cobalt, columbium, copper, molybdenum, nickel, phosphorus, titanium, tungsten, vanadium, zirconium, and the rare earths impart specific characteristics and are usually added as ferroalloys.

United States ferroalloy production in 1989 was approximately 894,000 megagrams (Mg) (985,000 tons), substantially less than shipments in 1975 of approximately 1,603,000 megagrams (1,770,000 tons). In 1989, ferroalloys were produced in the U. S. by 28 companies, although 5 of those produced only ferrophosphorous as a byproduct of elemental phosphorous production.

12.4.2 Process Description

A typical ferroalloy plant is illustrated in Figure 12.4-1. A variety of furnace types, including submerged electric arc furnaces, exothermic (metallothermic) reaction furnaces, and electrolytic cells can be used to produce ferroalloys. Furnace descriptions and their ferroalloy products are given in Table 12.4-1.

12.4.2.1 Submerged Electric Arc Process -

In most cases, the submerged electric arc furnace produces the desired product directly. It may produce an intermediate product that is subsequently used in additional processing methods. The submerged arc process is a reduction smelting operation. The reactants consist of metallic ores (ferrous oxides, silicon oxides, manganese oxides, chrome oxides, etc.) and a carbon-source reducing agent, usually in the form of coke, charcoal, high- and low-volatility coal, or wood chips. Limestone may also be added as a flux material. Raw materials are crushed, sized, and, in some cases, dried, and then conveyed to a mix house for weighing and blending. Conveyors, buckets, skip hoists, or cars transport the processed material to hoppers above the furnace. The mix is then gravity-fed through a feed chute either continuously or intermittently, as needed. At high temperatures in the reaction zone, the carbon source reacts with metal oxides to form carbon monoxide and to reduce the ores to base metal. A typical reaction producing ferrosilicon is shown below:

$$Fe_2O_3 + 2SiO_2 + 7C \rightarrow 2FeSi + 7CO$$
 (1)



Figure 12.4-1. Typical ferroalloy production process. (Source Classification Code in parentheses.)

Process	Product
Submerged arc furnace ^a	Silvery iron (15-22% Si) Ferrosilicon (50% Si) Ferrosilicon (65-75% Si) Silicon metal Silicon/manganese/zirconium (SMZ) High carbon (HC) ferromanganese Siliconmanganese HC ferrochrome Ferrochrome/silicon FeSi (90% Si)
Exothermic ^b Silicon reduction	Low carbon (LC) ferrochrome, LC ferromanganese, medium carbon (MC) ferromanganese
Aluminum Reduction	Chromium metal, ferrotitanium, ferrocolumbium, ferovanadium
Mixed aluminothermal/silicothermal	Ferromolybdenum, ferrotungsten
Electrolytic ^c	Chromium metal, manganese metal
Vacuum furnace ^d	LC ferrochrome
Induction furnace ^e	Ferrotitanium

Table 12.4-1. FERROALLOY PROCESSES AND RESPECTIVE PRODUCT GROUPS

^a Process by which metal is smelted in a refractory-lined cup-shaped steel shell by submerged graphite electrodes.

^b Process by which molten charge material is reduced, in exothermic reaction, by addition of silicon, aluminum, or a combination of the 2.

c Process by which simple ions of a metal, usually chromium or manganese in an electrolyte, are plated on cathodes by direct low-voltage current.

^d Process by which carbon is removed from solid-state high-carbon ferrochrome within vacuum furnaces maintained at temperatures near melting point of alloy.

^e Process that converts electrical energy into heat, without electrodes, to melt metal charges in a cup or drum-shaped vessel.

Smelting in an electric arc furnace is accomplished by conversion of electrical energy to heat. An alternating current applied to the electrodes causes current to flow through the charge between the electrode tips. This provides a reaction zone at temperatures up to 2000°C (3632°F). The tip of each electrode changes polarity continuously as the alternating current flows between the tips. To maintain a uniform electric load, electrode depth is continuously varied automatically by mechanical or hydraulic means.

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A typical submerged electric arc furnace design is depicted in Figure 12.4-2. The lower part of the submerged electric arc furnace is composed of a cylindrical steel shell with a flat bottom or hearth. The interior of the shell is lined with 2 or more layers of carbon blocks. The furnace shell may be water-cooled to protect it from the heat of the process. A water-cooled cover and fume collection hood are mounted over the furnace shell. Normally, 3 carbon electrodes arranged in a triangular formation extend through the cover and into the furnace shell opening. Prebaked or selfbaking (Soderberg) electrodes ranging from 76 to over 100 cm (30 to over 40 inches) in diameter are typically used. Raw materials are sometimes charged to the furnace through feed chutes from above the furnace. The surface of the furnace charge, which contains both molten material and unconverted charge during operation, is typically maintained near the top of the furnace shell. The lower ends of the electrodes are maintained at about 0.9 to 1.5 meters (3 to 5 feet) below the charge surface. Three-phase electric current arcs from electrode to electrode, passing through the charge material. The charge material melts and reacts to form the desired product as the electric energy is converted into heat. The carbonaceous material in the furnace charge reacts with oxygen in the metal oxides of the charge and reduces them to base metals. The reactions produce large quantities of carbon monoxide (CO) that passes upward through the furnace charge. The molten metal and slag are removed (tapped) through 1 or more tap holes extending through the furnace shell at the hearth level. Feed materials may be charged continuously or intermittently. Power is applied continuously. Tapping can be intermittent or continuous based on production rate of the furnace.

Submerged electric arc furnaces are of 2 basic types, open and covered. Most of the submerged electric arc furnaces in the U. S. are open furnaces. Open furnaces have a fume collection hood at least 1 meter (3.3 feet) above the top of the furnace shell. Moveable panels or screens are sometimes used to reduce the open area between the furnace and hood, and to improve emissions capture efficiency. Carbon monoxide rising through the furnace charge burns in the area between the charge surface and the capture hood. This substantially increases the volume of gas the containment system must handle. Additionally, the vigorous open combustion process entrains finer material in the charge. Fabric filters are typically used to control emissions from open furnaces.

Covered furnaces may have a water-cooled steel cover that fits closely to the furnace shell. The objective of covered furnaces is to reduce air infiltration into the furnace gases, which reduces combustion of that gas. This reduces the volume of gas requiring collection and treatment. The cover has holes for the charge and electrodes to pass through. Covered furnaces that partially close these hood openings with charge material are referred to as "mix-sealed" or "semi-enclosed furnaces". Although these covered furnaces significantly reduce air infiltration, some combustion still occurs under the furnace cover. Covered furnaces that have mechanical seals around the electrodes and sealing compounds around the outer edges are referred to as "sealed" or "totally closed". These furnaces have little, if any, air infiltration and undercover combustion. Water leaks from the cover into the furnace must be minimized as this leads to excessive gas production and unstable furnace operation. Products prone to highly variable releases of process gases are typically not made in covered furnaces for safety reasons. As the degree of enclosure increases, less gas is produced for capture by the hood system and the concentration of carbon monoxide in the furnace gas increases. Wet scrubbers are used to control emissions from covered furnaces. The scrubbed, high carbon monoxide content gas may be used within the plant or flared.

The molten alloy and slag that accumulate on the furnace hearth are removed at 1 to 5-hour intervals through the tap hole. Tapping typically lasts 10 to 15 minutes. Tap holes are opened with pellet shot from a gun, by drilling, or by oxygen lancing. The molten metal and slag flow from the tap hole into a carbon-lined trough, then into a carbon-lined runner that directs the metal and slag into a reaction ladle, ingot molds, or chills. (Chills are low, flat iron or steel pans that provide rapid

EMISSION FACTORS

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Figure 12.4-2. Typical submerged arc furnace design.

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cooling of the molten metal.) After tapping is completed, the furnace is resealed by inserting a carbon paste plug into the tap hole.

Chemistry adjustments may be necessary after furnace smelting to achieve a specified product. Ladle treatment reactions are batch processes and may include metal and alloy additions.

During tapping, and/or in the reaction ladle, slag is skimmed from the surface of the molten metal. It can be disposed of in landfills, sold as road ballast, or used as a raw material in a furnace or reaction ladle to produce a chemically related ferroalloy product.

After cooling and solidifying, the large ferroalloy castings may be broken with drop weights or hammers. The broken ferroalloy pieces are then crushed, screened (sized), and stored in bins until shipment. In some instances, the alloys are stored in lump form in inventories prior to sizing for shipping.

12.4.2.2 Exothermic (Metallothermic) Process -

The exothermic process is generally used to produce high-grade alloys with low-carbon content. The intermediate molten alloy used in the process may come directly from a submerged electric arc furnace or from another type of heating device. Silicon or aluminum combines with oxygen in the molten alloy, resulting in a sharp temperature rise and strong agitation of the molten bath. Low- and medium-carbon content ferrochromium (FeCr) and ferromanganese (FeMn) are produced by silicon reduction. Aluminum reduction is used to produce chromium metal, ferrotitanium, ferrovanadium, and ferrocolumbium. Mixed alumino/silico thermal processing is used for producing ferromolybdenum and ferrotungsten. Although aluminum is more expensive than carbon or silicon, the products are purer. Low-carbon (LC) ferrochromium is typically produced by fusing chromium ore and lime in a furnace. A specified amount is then placed in a ladle (ladle No. 1). A known amount of an intermediate grade ferrochromesilicon is then added to the ladle. The reaction is extremely exothermic and liberates chromium from its ore, producing LC ferrochromium and a calcium silicate slag. This slag, which still contains recoverable chromium oxide, is reacted in a second ladle (ladle No. 2) with molten high-carbon ferrochromesilicon to produce the intermediate-grade ferrochromesilicon. Exothermic processes are generally carried out in open vessels and may have emissions similar to the submerged arc process for short periods while the reduction is occurring.

12.4.2.3 Electrolytic Processes -

Electrolytic processes are used to produce high-purity manganese and chromium. As of 1989, there were 2 ferroalloy facilities using electrolytic processes.

Manganese may be produced by the electrolysis of an electrolyte extracted from manganese ore or manganese-bearing ferroalloy slag. Manganese ores contain close to 50 percent manganese; furnace slag normally contains about 10 percent manganese. The process has 5 steps: (1) roasting the ore to convert it to manganese oxide (MnO), (2) leaching the roasted ore with sulfuric acid (H_2SO_4) to solubilize manganese, (3) neutralization and filtration to remove iron and aluminum hydroxides, (4) purifying the leach liquor by treatment with sulfide and filtration to remove a wide variety of metals, and (5) electrolysis.

Electrolytic chromium is generally produced from high-carbon ferrochromium. A large volume of hydrogen gas is produced by dissolving the alloy in sulfuric acid. The leachate is treated with ammonium sulfate and conditioned to remove ferrous ammonium sulfate and produce a chromealum for feed to the electrolysis cells. The electrolysis cells are well ventilated to reduce ambient hydrogen and hexavalent chromium concentrations in the cell rooms.

EMISSION FACTORS

12.4.3 Emissions And Controls

Particulate is generated from several activities during ferroalloy production, including raw material handling, smelting, tapping, and product handling. Organic materials are generated almost exclusively from the smelting operation. The furnaces are the largest potential sources of particulate and organic emissions. The emission factors are given in Tables 12.4-2 and 12.4-3. Size-specific emission factors for submerged arc ferroalloy furnaces are given in Tables 12.4-4 and 12.4-5.

Particulate emissions from electric arc furnaces in the form of fumes account for an estimated 94 percent of the total particulate emissions in the ferroalloy industry. Large amounts of carbon monoxide and organic materials also are emitted by submerged electric arc furnaces. Carbon monoxide is formed as a byproduct of the chemical reaction between oxygen in the metal oxides of the charge and carbon contained in the reducing agent (coke, coal, etc.). Reduction gases containing organic compounds and carbon monoxide continuously rise from the high-temperature reaction zone, entraining fine particles and fume precursors. The mass weight of carbon monoxide produced sometimes exceeds that of the metallic product. The heat-induced fume consists of oxides of the products being produced and carbon from the reducing agent. The fume is enriched by silicon dioxide, calcium oxide, and magnesium oxide, if present in the charge.

In an open electric arc furnace, virtually all carbon monoxide and much of the organic matter burns with induced air at the furnace top. The remaining fume, captured by hooding about 1 meter above the furnace, is directed to a gas cleaning device. Fabric filters are used to control emissions from 85 percent of the open furnaces in the U. S. Scrubbers are used on 13 percent of the furnaces, and electrostatic precipitators on 2 percent.

Two emission capture systems, not usually connected to the same gas cleaning device, are necessary for covered furnaces. A primary capture system withdraws gases from beneath the furnace cover. A secondary system captures fumes released around the electrode seals and during tapping. Scrubbers are used almost exclusively to control exhaust gases from sealed furnaces. The scrubbers capture a substantial percentage of the organic emissions, which are much greater for covered furnaces than open furnaces. The gas from sealed and mix-sealed furnaces is usually flared at the exhaust of the scrubber. The carbon monoxide-rich gas is sometimes used as a fuel in kilns and sintering machines. The efficiency of flares for the control of carbon monoxide and the reduction of VOCs has been estimated to be greater than 98 percent. A gas heating reduction of organic and carbon monoxide emissions is 98 percent efficient.

Tapping operations also generate fumes. Tapping is intermittent and is usually conducted during 10 to 20 percent of the furnace operating time. Some fumes originate from the carbon lip liner, but most are a result of induced heat transfer from the molten metal or slag as it contacts the runners, ladles, casting beds, and ambient air. Some plants capture these emissions to varying degrees with a main canopy hood. Other plants employ separate tapping hoods ducted to either the furnace emission control device or a separate control device. Emission factors for tapping emissions are unavailable due to lack of data.

After furnace tapping is completed, a reaction ladle may be used to adjust the metallurgy by chlorination, oxidation, gas mixing, and slag metal reactions. Ladle reactions are an intermittent process, and emissions have not been quantified. Reaction ladle emissions are often captured by the tapping emissions control system.

Table 12.4-2 (Metric Units). EMISSION FACTORS FOR PARTICULATE FROM SUBMERGED ARC FERROALLOY FURNACES^a

Product ^b	Furnace Type	Particulate Emission Factors Uncontrolled ^c	EMISSION FACTOR RATING	Control Device ^d	Particulate Emission Factors Controlled ^c	EMISSION FACTOR RATING
FeSi (50%) (SCC 3-03-006-01)	Open ^{e,f,g}	35	В	Baghouse ^{c,f}	0.9	В
	Covered ^h	46	E	Scrubber ^{h,j} High energy Low energy	0.24 4.5	E E
FeSi (75%) (SCC 3-03-006-02)	Open ^k	158	E	Scrubber ^{h,j} Low energy	4.0	E
	Covered ^{h,j}	103	Е	ND	ND	NA
FeSi (90%) (SCC 3-03-006-03)	Open ^m	282	Е	ND	ND	NA
Si metal (98%) (SCC 3-03-006-04)	Open ^{n,p}	436	В	Baghouse ^{n,p}	16	В
FeMn (80%) (SCC 3-03-006-06)	Open ^{q,r}	14	В	Baghouse ^{q,r} Scrubber ^{h,s}	0.24	В
				High energy	0.8	Е
FeMn (1% Si) (SCC 3-03-007-01)	Covered ^{h,t}	6	E	E Scrubber High energy ^{h,s,w}		C
	Sealed ^{u,v}	37	E	ND	ND	NA
FeCr (high carbon) (SCC 3-03-006-07)	Open ^{x,y}	78	с	ESP ^{x,y}	1.2	с
SiMn (SCC 3-03-006-05)	Open ^{z, aa}	96	с	Scrubber ^{aa,bb}	2.1	с
	Sealed	_	—	Scrubber ^{v,w} High energy	0.15	с

^a Emission factors are expressed as kg of pollutant/Mg alloy produced. Factors are for main furnace dust collection system before and after control device. Where other emissions, such as leaks or tapping, are included or quantified separately, such is noted. Particulate sources not included: raw material handling, storage, and preparation; and product crushing, screening, handling, and packaging. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Percentages are of the main alloying agent in product.

12.4-8

Table 12.4-2 (cont.).

- ^c In most source testing, fugitive emissions are not measured or collected. Where tapping emissions are controlled by primary system, their contribution to total emissions could not be determined. Fugitive emissions may vary greatly among sources, with furnace and collection system design and operating practices.
- ^d Low-energy scrubbers are those with $\triangle P < 20$ inches of H₂O; high-energy with $\triangle P > 20$ inches of H₂O.
- ^e Includes fumes captured by tapping hood (efficiency estimated at near 100%).
- ^f References 4, 10, 21.
- ^g Factor is average of 3 sources, fugitive emissions not included. Fugitive emissions at 1 source measured an additional 10.5 kg/Mg alloy, or 2.7 kg/MW-hr.
- ^h References 4,10.
- ^j Does not include emissions from tapping or mix seal leaks.
- ^k References 25-26.
- ^m Reference 23.
- ⁿ Estimated 60% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).
- ^p References 10,13.
- ^q Estimated 50% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).
- ^r References 4,10,12.
- ^s Includes fumes only from primary control system.
- ^t Includes tapping fumes and mix seal leak fugitive emissions. Fugitive emissions measured at 33% of total uncontrollable emissions.
- ^u Assumes tapping fumes not included in emission factor.
- ^v Reference 14.
- ^w Does not include tapping or fugitive emissions.
- ^x Tapping emissions included.
- ^y References 2,15-17.
- ^z Factor is average of 2 test series. Tests at 1 source included fugitive emissions (3.4% of total uncontrolled emissions). Second test insufficient to determine if fugitive emissions were included in total.
- ^{aa} References 2,18-19.
- ^{bb} Factors developed from 2 scrubber controlled sources, 1 operated at $\triangle P = 47-57$ inches of H₂O, the other at unspecified $\triangle P$. Uncontrolled tapping operations emissions are 2.1 kg/Mg alloy.

Table 12.4-3 (English Units).	EMISSION.FACTORS	FOR PARTICULATE FROM
SUBMERGE	D ARC FERROALLOY	FURNACES ^a

Product ^b	Furnace Type	Particulate Emission factors Uncontrolled ^c	EMISSION FACTOR RATING	Control Device ^d	Particulate Emission factors Controlled ^c	EMISSION FACTOR RATING
FeSi (50%) (SCC 3-03-006-01)	Open ^{e,f,g}	70	В	Baghouse ^{c, f}	1.8	В
	Covered ^h	92	Е	Scrubber ^{h,j} High energy Low energy	0.48 9.0	E E
FeSi (75%) (SCC 3-03-006-02)	Open ^k	316	Е	Scrubber ^{h,j} Low energy	8.0	Е
	Covered ^{h,j}	206	Е	ND	ND	NA
FeSi (90%) (SCC 3-03-006-03)	Open ^m	564	Е	ND	ND	NA
Si metal (98%) (SCC 3-03-006-04)	Open ^{n,p}	872	В	Baghouse ^{n,p}	32	В
FeMn (80%) (SCC 3-03-006-06)	Open ^{q, r}	28	В	Baghouse ^{q,r} Scrubber ^{h,s}	0.48	В
				High energy	1.6	Е
FeMn (1% Si) (SCC 3-03-007-01)	Covered ^{h,t}	12	Е	Scrubber High energy ^{h, s, w}	0.5	С
	Sealed ^{u,v}	74	Е	ND	ND	NA
FeCr (high carbon) (SCC 3-03-006-07)	Open ^{x,y}	157	С	ESP ^{x,y}	2.3	С
SiMn (SCC 3-03-006-05)	Open ^{z,aa}	192	с	Scrubber ^{aa,bb}	4.2	С
	Sealed	_	_	Scrubber ^{v,w} High energy	0.30	С

^a Emission factors expressed as 1b of pollutant/ton of Alloy produced. Factors are for main furnace dust collection system before and after control device. Where other emissions, such as leaks or tapping, are included or quantified separately, such is noted. Particulate sources not included: raw material handling, storage, and preparation; and product crushing, screening, handling, and packaging. SCC = Source Classification Code. ND = no data. NA = not applicable. ^b Percentages are of the main alloying agent in product.

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Table 12.4-3 (cont.).

- ^c In most source testing, fugitive emissions are not measured or collected. Where tapping emissions are controlled by primary system, their contribution to total emissions could not be determined. Fugitive emissions may vary greatly among sources, with furnace and collection system design and operating practices.
- ^d Low-energy scrubbers are those with $\triangle P < 20$ inches of H₂O; high-energy with $\triangle P > 20$ inches of H₂O.
- ^e Includes fumes captured by tapping hood (efficiency estimated at near 100%).
- f References 4,10,21.
- ^g Factor is average of 3 sources, fugitive emissions not included. Fugitive emissions at 1 source measured an additional 21 lb/ton alloy, or 5.9 lb/MW-hr.
- ^h References 4,10.
- ^j Does not include emissions from tapping or mix seal leaks.
- ^k References 25-26.
- ^m Reference 23.
- ⁿ Estimated 60% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).
- ^p References 10,13.
- ^q Estimated 50% of tapping emissions captured by control system (escaped fugitive emissions not included in factor).
- ^r References 4,10,12.
- ^s Includes fumes only from primary control system.
- ^t Includes tapping fumes and mix seal leak fugitive emissions. Fugitive emissions measured at 33% of total uncontrollable emissions.
- ^u Assumes tapping fumes not included in emission factor.
- ^v Reference 14.
- ^w Does not include tapping or fugitive emissions.
- ^x Tapping emissions included.
- ^y References 2,15-17.
- ^z Factor is average of 2 test series. Tests at 1 source included fugitive emissions (3.4% of total uncontrolled emissions). Second test insufficient to determine if fugitive emissions were included in total.

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- ^{aa} References 2,18-19.
- ^{bb} Factors developed from 2 scrubber controlled sources, 1 operated at $\triangle P = 47-57$ inches of H₂O, the other at unspecified $\triangle P$. Uncontrolled tapping operations emissions are 4.2 lb/ton alloy.

Product	Control Device	Particle Size ^a (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (kg/Mg alloy)	EMISSION FACTOR RATING
50% FeSi Open furnace (SCC 3-03-006-01)	None ^{b,c}	0.63 1.00 1.25 2.50 6.00 10.00 15.00 20.00 d	45 50 53 57 61 63 66 69 100	16 18 19 20 21 22 23 24 35	В
	Baghouse	0.63 1.00 1.25 2.50 6.00 10.00 15.00 20.00	31 39 44 54 63 72 80 85 100	0.28 0.35 0.40 0.49 0.57 0.65 0.72 0.77 0.90	В
80% FeMn Open furnace (SCC 3-03-006-06)	None ^{e, f}	0.63 1.00 1.25 2.50 6.00 10.00 15.00 20.00 d	30 46 52 62 72 86 96 97 100	4 7 8 9 10 12 13 14 14	В
	Baghouse ^e	0.63 1.00 1.25 2.50 6.00 10.00 15.00 20.00 d	20 30 35 49 67 83 92 97 100	$\begin{array}{c} 0.048\\ 0.070\\ 0.085\\ 0.120\\ 0.160\\ 0.200\\ 0.220\\ 0.235\\ 0.240\\ \end{array}$	В

Table 12.4-4 (Metric Units). SIZE-SPECIFIC EMISSION FACTORS FOR SUBMERGED ARC FERROALLOY FURNACES

EMISSION FACTORS

Product	Control Device	Particle Size ^a (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (kg/Mg alloy)	EMISSION FACTOR RATING
Si Metal ^g Open furnace (SCC 3-03-006-04)	None ^h Baghouse	0.63 1.00 1.25 2.50 6.00 10.00 15.00 20.00 d 1.00	57 67 70 75 80 86 91 95 100 49	249 292 305 327 349 375 397 414 436 7.8	В
FeCr (HC)	Lugnouse	1.25 2.50 6.00 10.00 15.00 20.00	53 64 76 87 96 99 100	8.5 10.2 12.2 13.9 15.4 15.8 16.0	
Open furnace (SCC 3-03-006-07)	None ^{b j}	0.5 1.0 2.0 2.5 4.0 6.0 10.0 d	19 36 60 63 ^k 76 88 ^k 91 100	15 28 47 49 59 67 71 78	С
	ESP	0.5 1.0 2.0 2.5 4.0 6.0 10.0 d	33 47 67 80 86 90 100	0.40 0.56 0.80 0.96 1.03 1.08 1.2	С

Table 12.4-4 (cont.).

Product	Control Device	Particle Size ^a (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (kg/Mg alloy)	EMISSION FACTOR RATING
SiMn Open furnace (SCC 3-03-006-05)	None ^{b,m}	0.5 1.0 2.0 2.5 4.0 6.0 10.0 d	28 44 60 65 76 85 96 ^k 100	27 42 58 62 73 82 92 ^k 96	С
	Scrubber ^{m,n}	0.5 1.0 2.0 2.5 4.0 6.0 10.0	56 80 96 99 99.5 99.9 ^k 100	1.18 1.68 2.02 2.08 2.09 2.10 ^k 2.1	С

Table 12.4-4 (cont.).

^a Aerodynamic diameter, based on Task Group On Lung Dynamics definition.
 Particle density = 1 g/cm³.

- ^b Includes tapping emissions.
- ^c References 4,10,21.
- ^d Total particulate, based on Method 5 total catch (see Tables 12.4-2 and 12.4-3).
- ^e Includes tapping fumes (estimated capture efficiency 50%).
- f References 4, 10, 12.
- ^g References 10,13.
- ^h Includes tapping fumes (estimated capture efficiency 60%).
- ^j References 1,15-17.
- ^k Interpolated data.
- ^m References 2,18-19.
- ⁿ Primary emission control system only, without tapping emissions.

Table 12.4-5 (English Units). SIZE-SPECIFIC EMISSION FACTORS FOR SUBMERGED ARC FERROALLOY FURNACES

Product	Control Device	Particle Size ^a (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (lb/ton alloy)	EMISSION FACTOR RATING
50% FeSi Open furnace (SCC 3-03-006-01)	None ^{b,c} Baghouse	$\begin{array}{c} 0.63 \\ 1.00 \\ 1.25 \\ 2.50 \\ 6.00 \\ 10.00 \\ 15.00 \\ 20.00 \\ -^{d} \\ 0.63 \end{array}$	45 50 53 57 61 63 66 69 100 31	32 35 37 40 43 44 46 48 70 0.56	В
		$ \begin{array}{r} 1.00\\ 1.25\\ 2.50\\ 6.00\\ 10.00\\ 15.00\\ 20.00 \end{array} $	39 44 54 63 72 80 85 100	0.70 0.80 1.0 1.1 1.3 1.4 1.5 1.8	
80% FeMn Open furnace (SCC 3-03-006-06)	None ^{e,f}	0.63 1.00 1.25 2.50 6.00 10.00 15.00 20.00 d	30 46 52 62 72 86 96 97 100	8 13 15 17 20 24 26 27 28	В
	Baghouse ^e	0.63 1.00 1.25 2.50 6.00 10.00 15.00 20.00 d	20 30 35 49 67 83 92 97 100	0.10 0.14 0.17 0.24 0.32 0.40 0.44 0.47 0.48	В

Product	Control Device	Particle Size ^a (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (lb/ton alloy)	EMISSION FACTOR RATING
Si Metal ^g Open Furnace (SCC 3-03-006-04)	None ^h	0.63 1.00 1.25 2.50 6.00 10.00 15.00 20.00 d	57 67 70 75 80 86 91 95 100	497 584 610 654 698 750 794 828 872	В
	Baghouse	$ \begin{array}{r} 1.00\\ 1.25\\ 2.50\\ 6.00\\ 10.00\\ 15.00\\ 20.00 \end{array} $	49 53 64 76 87 96 99 100	15.7 17.0 20.5 24.3 28.0 31.0 31.7 32.0	В
FeCr (HC) Open furnace (SCC 3-03-006-07)	None ^{b j}	0.5 1.0 2.0 2.5 4.0 6.0 10.0 d	19 36 60 63 ^k 76 88 ^k 91 100	30 57 94 99 119 138 143 157	С
	ESP	0.5 1.0 2.0 2.5 4.0 6.0 10.0 d	33 47 67 80 86 90 100	0.76 1.08 1.54 1.84 1.98 2.07 2.3	С

Table 12.4-5 (cont.).

Table	12.4-5	(cont.).
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Product	Control Device	Particle Size ^a (µm)	Cumulative Mass % ≤ Stated Size	Cumulative Mass Emission Factor (lb/ton alloy)	EMISSION FACTOR RATING
SiMn Open furnace (SCC 3-05-006-05)	None ^{b,m}	0.5 1.0 2.0 2.5 4.0 6.0 10.0 d	28 44 60 65 76 85 96 ^k 100	54 84 115 125 146 163 177 ^k 192	С
	Scrubber ^{m,n}	0.5 1.0 2.0 2.5 4.0 6.0 10.0	56 80 96 99 99.5 99.9 ^k 100	2.36 3.34 4.03 4.16 4.18 4.20 ^k 4.3	С

Aerodynamic diameter, based on Task Group On Lung Dynamics definition.
 Particle density = 1 g/cm³.

- ^b Includes tapping emissions.
- ^c References 4,10,21.
- ^d Total particulate, based on Method 5 total catch (see Tables 12.4-2 and 12.4-3).
- ^e Includes tapping fumes (estimated capture efficiency 50%).
- f References 4, 10, 12.
- g References 10,13.
- ^h Includes tapping fumes (estimated capture efficiency 60%).
- ^j References 1,15-17.
- ^k Interpolated data.
- ^m References 2,18-19.
- ⁿ Primary emission control system only, without tapping emissions.

Available data are insufficient to provide emission factors for raw material handling, pretreatment, and product handling. Dust particulate is emitted from raw material handling, storage, and preparation activities (see Figure 12.4-1). These activities include unloading raw materials from delivery vehicles (ship, railway car, or truck), storing raw materials in piles, loading raw materials from storage piles into trucks or gondola cars, and crushing and screening raw materials. Raw materials may be dried before charging in rotary or other types of dryers, and these dryers can generate significant particulate emissions. Dust may also be generated by heavy vehicles used for loading, unloading, and transferring material. Crushing, screening, and storage of the ferroalloy product emit particulate matter in the form of dust. The properties of particulate matter emitted as dust are similar to the natural properties of the ores or alloys from which they originated, ranging in size from 3 to 100 micrometers (μ m).

Approximately half of all ferroalloy facilities have some type of control for dust emissions. Dust generated from raw material storage may be controlled in several ways, including sheltering storage piles from the wind with block walls, snow fences, or plastic covers. Occasionally, piles are sprayed with water to prevent airborne dust. Emissions generated by heavy vehicle traffic may be reduced by using a wetting agent or paving the plant yard. Moisture in the raw materials, which may be as high as 20 percent; helps to limit dust emissions from raw material unloading and loading. Dust generated by crushing, sizing, drying, or other pretreatment activities may be controlled by dust collection equipment such as scrubbers, cyclones, or fabric filters. Ferroalloy product crushing and sizing usually require a fabric filter. The raw material emission collection equipment may be connected to the furnace emission control system. For fugitive emissions from open sources, see Section 13.2 of this document.

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12.5 Iron And Steel Production

12.5.1 Process Description¹⁻³

The production of steel at an integrated iron and steel plant is accomplished using several interrelated processes. The major operations are: (1) coke production, (2) sinter production, (3) iron production, (4) iron preparation, (5) steel production, (6) semifinished product preparation, (7) finished product preparation, (8) heat and electricity supply, and (9) handling and transport of raw, intermediate, and waste materials. The interrelation of these operations is depicted in a general flow diagram of the iron and steel industry in Figure 12.5-1. Coke production is discussed in detail in Section 12.2 of this publication, and more information on the handling and transport of materials is found in Chapter 13.

12.5.1.1 Sinter Production -

The sintering process converts fine-sized raw materials, including iron ore, coke breeze, limestone, mill scale, and flue dust, into an agglomerated product, sinter, of suitable size for charging into the blast furnace. The raw materials are sometimes mixed with water to provide a cohesive matrix, and then placed on a continuous, travelling grate called the sinter strand. A burner hood, at the beginning of the sinter strand ignites the coke in the mixture, after which the combustion is self supporting and it provides sufficient heat, 1300 to 1480°C (2400 to 2700°F), to cause surface melting and agglomeration of the mix. On the underside of the sinter strand is a series of windboxes that draw combusted air down through the material bed into a common duct, leading to a gas cleaning device. The fused sinter is discharged at the end of the sinter strand, where it is crushed and screened. Undersize sinter is recycled to the mixing mill and back to the strand. The remaining sinter product is cooled in open air or in a circular cooler with water sprays or mechanical fans. The cooled sinter is crushed and screened for a final time, then the fines are recycled, and the product is sent to be charged to the blast furnaces. Generally, 2.3 Mg (2.5 tons) of raw materials, including water and fuel, are required to produce 0.9 Mg (1 ton) of product sinter.

12.5.1.2 Iron Production -

Iron is produced in blast furnaces by the reduction of iron bearing materials with a hot gas. The large, refractory lined furnace is charged through its top with iron as ore, pellets, and/or sinter; flux as limestone, dolomite, and sinter; and coke for fuel. Iron oxides, coke and fluxes react with the blast air to form molten reduced iron, carbon monoxide (CO), and slag. The molten iron and slag collect in the hearth at the base of the furnace. The byproduct gas is collected through offtakes located at the top of the furnace and is recovered for use as fuel.

The production of 1 ton of iron requires 1.4 tons of ore or other iron bearing material; 0.5 to 0.65 tons of coke; 0.25 tons of limestone or dolomite; and 1.8 to 2 tons of air. Byproducts consist of 0.2 to 0.4 tons of slag, and 2.5 to 3.5 tons of blast furnace gas containing up to 100 pounds (lb) of dust.

The molten iron and slag are removed, or cast, from the furnace periodically. The casting process begins with drilling a hole, called the taphole, into the clay-filled iron notch at the base of the hearth. During casting, molten iron flows into runners that lead to transport ladles. Slag also flows into the clay-filled iron notch at the base of the hearth. During casting, molten iron flows into runners that lead to transport ladles. Slag also flows into runners that lead to transport ladles. Slag also flows from the furnace, and is directed through separate runners to a slag pit adjacent to the casthouse, or into slag pots for transport to a remote slag







Figure 12.5-1. General flow diagram for the iron and steel industry.

pit. At the conclusion of the cast, the taphole is replugged with clay. The area around the base of the furnace, including all iron and slag runners, is enclosed by a casthouse. The blast furnace byproduct gas, which is collected from the furnace top, contains CO and particulate. Because of its high CO content, this blast furnace gas has a low heating value, about 2790 to 3350 joules per liter (J/L) (75 to 90 British thermal units per cubic foot $[Btu/ft^3]$) and is used as a fuel within the steel plant. Before it can be efficiently oxidized, however, the gas must be cleaned of particulate. Initially, the gases pass through a settling chamber or dry cyclone to remove about 60 percent of the particulate. Next, the gases undergo a 1- or 2-stage cleaning operation. The primary cleaner is normally a wet scrubber, which removes about 90 percent of the remaining particulate. The secondary cleaner is a high-energy wet scrubber (usually a venturi) or an electrostatic precipitator, either of which can remove up to 90 percent of the particulate that eludes the primary cleaner. Together these control devices provide a clean fuel of less than 0.05 grams per cubic meter (g/m^3) (0.02 grains per cubic foot $[g/ft^3]$). A portion of this gas is fired in the blast furnace stoves to preheat the blast air, and the rest is used in other plant operations.

12.5.1.3 Iron Preparation Hot Metal Desulfurization -

Sulfur in the molten iron is sometimes reduced before charging into the steelmaking furnace by adding reagents. The reaction forms a floating slag which can be skimmed off. Desulfurization may be performed in the hot metal transfer (torpedo) car at a location between the blast furnace and basic oxygen furnace (BOF), or it may be done in the hot metal transfer (torpedo) ladle at a station inside the BOF shop.

The most common reagents are powdered calcium carbide (CaC_2) and calcium carbonate $(CaCO_3)$ or salt-coated magnesium granules. Powdered reagents are injected into the metal through a lance with high-pressure nitrogen. The process duration varies with the injection rate, hot metal chemistry, and desired final sulfur content, and is in the range of 5 to 30 minutes.

12.5.1.4 Steelmaking Process - Basic Oxygen Furnaces -

In the basic oxygen process (BOP), molten iron from a blast furnace and iron scrap are refined in a furnace by lancing (or injecting) high-purity oxygen. The input material is typically 70 percent molten metal and 30 percent scrap metal. The oxygen reacts with carbon and other impurities to remove them from the metal. The reactions are exothermic, i. e., no external heat source is necessary to melt the scrap and to raise the temperature of the metal to the desired range for tapping. The large quantities of CO produced by the reactions in the BOF can be controlled by combustion at the mouth of the furnace and then vented to gas cleaning devices, as with open hoods, or combustion can be suppressed at the furnace mouth, as with closed hoods. BOP steelmaking is conducted in large (up to 363 Mg [400 ton] capacity) refractory lined pear shaped furnaces. There are 2 major variations of the process. Conventional BOFs have oxygen blown into the top of the furnace through a water-cooled lance. In the newer, Quelle Basic Oxygen process (Q-BOP), oxygen is injected through tuyeres located in the bottom of the furnace. A typical BOF cycle consists of the scrap charge, hot metal charge, oxygen blow (refining) period, testing for temperature and chemical composition of the steel, alloy additions and reblows (if necessary), tapping, and slagging. The full furnace cycle typically ranges from 25 to 45 minutes.

12.5.1.5 Steelmaking Process - Electric Arc Furnace -

Electric arc furnaces (EAF) are used to produce carbon and alloy steels. The input material to an EAF is typically 100 percent scrap. Cylindrical, refractory lined EAFs are equipped with carbon electrodes to be raised or lowered through the furnace roof. With electrodes retracted, the furnace roof can be rotated aside to permit the charge of scrap steel by overhead crane. Alloying agents and fluxing materials usually are added through the doors on the side of the furnace. Electric

current of the opposite polarity electrodes generates heat between the electrodes and through the scrap. After melting and refining periods, the slag and steel are poured from the furnace by tilting.

The production of steel in an EAF is a batch process. Cycles, or "heats", range from about 1-1/2 to 5 hours to produce carbon steel and from 5 to 10 hours or more to produce alloy steel. Scrap steel is charged to begin a cycle, and alloying agents and slag materials are added for refining. Stages of each cycle normally are charging and melting operations, refining (which usually includes oxygen blowing), and tapping.

12.5.1.6 Steelmaking Process - Open Hearth Furnaces -

The open hearth furnace (OHF) is a shallow, refractory-lined basin in which scrap and molten iron are melted and refined into steel. Scrap is charged to the furnace through doors in the furnace front. Hot metal from the blast furnace is added by pouring from a ladle through a trough positioned in the door. The mixture of scrap and hot metal can vary from all scrap to all hot metal, but a halfand-half mixture is most common. Melting heat is provided by gas burners above and at the side of the furnace. Refining is accomplished by the oxidation of carbon in the metal and the formation of a limestone slag to remove impurities. Most furnaces are equipped with oxygen lances to speed up melting and refining. The steel product is tapped by opening a hole in the base of the furnace with an explosive charge. The open hearth steelmaking process with oxygen lancing normally requires from 4 to 10 hours for each heat.

12.5.1.7 Semifinished Product Preparation -

After the steel has been tapped, the molten metal is teemed (poured) into ingots which are later heated and formed into other shapes, such as blooms, billets, or slabs. The molten steel may bypass this entire process and go directly to a continuous casting operation. Whatever the production technique, the blooms, billets, or slabs undergo a surface preparation step, scarfing, which removes surface defects before shaping or rolling. Scarfing can be performed by a machine applying jets of oxygen to the surface of hot semifinished steel, or by hand (with torches) on cold or slightly heated semifinished steel.

12.5.2 Emissions And Controls

12.5.2.1 Sinter -

Emissions from sinter plants are generated from raw material handling, windbox exhaust, discharge end (associated sinter crushers and hot screens), cooler, and cold screen. The windbox exhaust is the primary source of particulate emissions, mainly iron oxides, sulfur oxides, carbonaceous compounds, aliphatic hydrocarbons, and chlorides. At the discharge end, emissions are mainly iron and calcium oxides. Sinter strand windbox emissions commonly are controlled by cyclone cleaners followed by a dry or wet ESP, high pressure drop wet scrubber, or baghouse. Crusher and hot screen emissions, usually controlled by hooding and a baghouse or scrubber, are the next largest emissions source. Emissions are also generated from other material handling operations. At some sinter plants, these emissions are captured and vented to a baghouse.

12.5.2.2 Blast Furnace -

The primary source of blast furnace emissions is the casting operation. Particulate emissions are generated when the molten iron and slag contact air above their surface. Casting emissions also are generated by drilling and plugging the taphole. The occasional use of an oxygen lance to open a clogged taphole can cause heavy emissions. During the casting operation, iron oxides, magnesium oxide and carbonaceous compounds are generated as particulate. Casting emissions at existing blast furnaces are controlled by evacuation through retrofitted capture hoods to a gas cleaner, or by suppression techniques. Emissions controlled by hoods and an evacuation system are usually vented

to a baghouse. The basic concept of suppression techniques is to prevent the formation of pollutants by excluding ambient air contact with the molten surfaces. New furnaces have been constructed with evacuated runner cover systems and local hooding ducted to a baghouse.

Another potential source of emissions is the blast furnace top. Minor emissions may occur during charging from imperfect bell seals in the double bell system. Occasionally, a cavity may form in the blast furnace charge, causing a collapse of part of the burden (charge) above it. The resulting pressure surge in the furnace opens a relief valve to the atmosphere to prevent damage to the furnace by the high pressure created and is referred to as a "slip".

12.5.2.3 Hot Metal Desulfurization -

Emissions during the hot metal desulfurization process are created by both the reaction of the reagents injected into the metal and the turbulence during injection. The pollutants emitted are mostly iron oxides, calcium oxides, and oxides of the compound injected. The sulfur reacts with the reagents and is skimmed off as slag. The emissions generated from desulfurization may be collected by a hood positioned over the ladle and vented to a baghouse.

12.5.2.4 Steelmaking -

The most significant emissions from the BOF process occur during the oxygen blow period. The predominant compounds emitted are iron oxides, although heavy metals and fluorides are usually present. Charging emissions will vary with the quality and quantity of scrap metal charged to the furnace and with the pour rate. Tapping emissions include iron oxides, sulfur oxides, and other metallic oxides, depending on the grade of scrap used. Hot metal transfer emissions are mostly iron oxides.

BOFs are equipped with a primary hood capture system located directly over the open mouth of the furnaces to control emissions during oxygen blow periods. Two types of capture systems are used to collect exhaust gas as it leaves the furnace mouth: closed hood (also known as an off gas, or O. G., system) or open, combustion-type hood. A closed hood fits snugly against the furnace mouth, ducting all particulate and CO to a wet scrubber gas cleaner. CO is flared at the scrubber outlet stack. The open hood design allows dilution air to be drawn into the hood, thus combusting the CO in the hood system. Charging and tapping emissions are controlled by a variety of evacuation systems and operating practices. Charging hoods, tapside enclosures, and full furnace enclosures are used in the industry to capture these emissions and send them to either the primary hood gas cleaner or a second gas cleaner.

12.5.2.5 Steelmaking - Electric Arc Furnace -

The operations which generate emissions during the electric arc furnace steelmaking process are melting and refining, charging scrap, tapping steel, and dumping slag. Iron oxide is the predominant constituent of the particulate emitted during melting. During refining, the primary particulate compound emitted is calcium oxide from the slag. Emissions from charging scrap are difficult to quantify, because they depend on the grade of scrap utilized. Scrap emissions usually contain iron and other metallic oxides from alloys in the scrap metal. Iron oxides and oxides from the fluxes are the primary constituents of the slag emissions. During tapping, iron oxide is the major particulate compound emitted.

Emission control techniques involve an emission capture system and a gas cleaning system. Five emission capture systems used in the industry are fourth hold (direct shell) evacuation, side draft hood, combination hood, canopy hood, and furnace enclosures. Direct shell evacuation consists of ductwork attached to a separate or fourth hole in the furnace roof which draws emissions to a gas cleaner. The fourth hole system works only when the furnace is up-right with the roof in place. Side draft hoods collect furnace off gases from around the electrode holes and the work doors after the gases leave the furnace. The combination hood incorporates elements from the side draft and fourth hole venulation systems. Emissions are collected both from the fourth hole and around the electrodes. An air gap in the ducting introduces secondary air for combustion of CO in the exhaust gas. The combination hood requires careful regulation of furnace interval pressure. The canopy hood is the least efficient of the 4 ventilation systems, but it does capture emissions during charging and tapping. Many new electric arc furnaces incorporate the canopy hood with one of the other 3 systems. The full furnace enclosure completely surrounds the furnace and evacuates furnace emissions through hooding in the top of the enclosure.

12.5.2.6 Steelmaking - Open Hearth Furnace -

Particulate emissions from an open hearth furnace vary considerably during the process. The use of oxygen lancing increases emissions of dust and fume. During the melting and refining cycle, exhaust gas drawn from the furnace passes through a slag pocket and a regenerative checker chamber, where some of the particulate settles out. The emissions, mostly iron oxides, are then ducted to either an ESP or a wet scrubber. Other furnace-related process operations which produce fugitive emissions inside the shop include transfer and charging of hot metal, charging of scrap, tapping steel, and slag dumping. These emissions are usually uncontrolled.

12.5.2.7 Semifinished Product Preparation -

During this activity, emissions are produced when molten steel is poured (teamed) into ingot molds, and when semifinished steel is machine or manually scarfed to remove surface defects. Pollutants emitted are iron and other oxides (FeO, Fe_2O_3 , SiO_2 , CaO, MgO). Teeming emissions are rarely controlled. Machine scarfing operations generally use as ESP or water spray chamber for control. Most hand scarfing operations are uncontrolled.

12.5.2.8 Miscellaneous Combustion -

Every iron and steel plant operation requires energy in the form of heat or electricity. Combustion sources that produce emissions on plant property are blast furnace stoves, boilers, soaking pits, and reheat furnaces. These facilities burn combinations of coal, No. 2 fuel oil, natural gas, coke oven gas, and blast furnace gas. In blast furnace stoves, clean gas from the blast furnace is burned to heat the refractory checker work, and in turn, to heat the blast air. In soaking pits, ingots are heated until the temperature distribution over the cross-section of the ingots is acceptable and the surface temperature is uniform for further rolling into semifinished products (blooms, billets, and slabs). In slab furnaces, a slab is heated before being rolled into finished products (plates, sheets, or strips). Emissions from the combustion of natural gas, fuel oil, or coal in the soaking pits or slab furnaces are estimated to be the same as those for boilers. (See Chapter 1 of this document.) Emission factor data for blast furnace gas and coke oven gas are not available and must be estimated. There are 3 facts available for making the estimation. First, the gas exiting the blast furnace passes through primary and secondary cleaners and can be cleaned to less than 0.05 g/m^3 (0.02 g/ft^3). Second, nearly one-third of the coke oven gas is methane. Third, there are no blast furnace gas constituents that generate particulate when burned. The combustible constituent of blast furnace gas is CO, which burns clean. Based on facts 1 and 3, the emission factor for combustion of blast furnace gas is equal to the particulate loading of that fuel, 0.05 g/m^3 (2.9 lb/10⁶ ft³) having an average heat value of 3092 J/L (83 Btu/ft³).

Emissions for combustion of coke oven gas can be estimated in the same fashion. Assume that cleaned coke oven gas has as much particulate as cleaned blast furnace gas. Since one-third of the coke oven gas is methane, the main component of natural gas, it is assumed that the combustion of this methane in coke oven gas generates 0.06 g/m^3 (3.3 lb/10⁶ ft³) of particulate. Thus, the emission factor for the combustion of coke oven gas is the sum of the particulate loading and that

EMISSION FACTORS

generated by the methane combustion, or 0.1 g/m^3 (6.2 lb/10⁶ ft³) having an average heat value of 19,222 J/L (516 Btu/ft³).

The particulate emission factors for processes in Table 12.5-1 are the result of an extensive investigation by EPA and the American Iron and Steel Institute.³ Particle size distributions for controlled and uncontrolled emissions from specific iron and steel industry processes have been calculated and summarized from the best available data.¹ Size distributions have been used with particulate emission factors to calculate size-specific factors for the sources listed in Table 12.5-1 for which data are available. Table 12.5-2 presents these size-specific particulate emission factors. Particle size distributions are presented in Figure 12.5-2, Figure 12.5-3, and Figure 12.5-4.CO emission factors are in Table 12.5-3.⁶

12.5.2.9 Open Dust Sources -

Like process emission sources, open dust sources contribute to the atmospheric particulate burden. Open dust sources include vehicle traffic on paved and unpaved roads, raw material handling outside of buildings, and wind erosion from storage piles and exposed terrain. Vehicle traffic consists of plant personnel and visitor vehicles, plant service vehicles, and trucks handling raw materials, plant deliverables, steel products, and waste materials. Raw materials are handled by clamshell buckets, bucket/ladder conveyors, rotary railroad dumps, bottom railroad dumps, front end loaders, truck dumps, and conveyor transfer stations, all of which disturb the raw material and expose fines to the wind. Even fine materials, resting on flat areas or in storage piles are exposed and are subject to wind erosion. It is not unusual to have several million tons of raw materials stored at a plant and to have in the range of 9.7 to 96.7 hectares (10 to 100 acres) of exposed area there.

Open dust source emission factors for iron and steel production are presented in Table 12.5-4. These factors were determined through source testing at various integrated iron and steel plants.

As an alternative to the single-valued open dust emission factors given in Table 12.5-4, empirically derived emission factor equations are presented in Section 13.2 of this document. Each equation was developed for a source operation defined on the basis of a single dust generating mechanism which crosses industry lines, such as vehicle traffic on unpaved roads. The predictive equation explains much of the observed variance in measured emission factors by relating emissions to parameters which characterize source conditions. These parameters may be grouped into 3 categories: (1) measures of source activity or energy expended (e. g., the speed and weight of a vehicle traveling on an unpaved road), (2) properties of the material being disturbed (e. g., the content of suspendible fines in the surface material on an unpaved road) and (3) climatic parameters (e. g., number of precipitation free days per year, when emissions tend to a maximum).⁴

Because the predictive equations allow for emission factor adjustment to specific source conditions, the equations should be used in place of the factors in Table 12.5-4, if emission estimates for sources in a specific iron and steel facility are needed. However, the generally higher-quality ratings assigned to the equations are applicable only if (1) reliable values of correction parameters have been determined for the specific sources of interest and (2) the correction parameter values lie within the ranges tested in developing the equations. Section 13.2 lists measured properties of aggregate process materials and road surface materials in the iron and steel industry, which can be used to estimate correction parameter values for the predictive emission factor equations, in the event that site-specific values are not available.

Use of mean correction parameter values from Section 13.2 reduces the quality ratings of the emission factor equation by one level.

Table 12.5-1 (Metric And English Units). PARTICULATE EMISSION FACTORS FOR IRON AND STEEL MILLS^a

Source	Units	Emission Factor		EMISSION FACTOR RATING	Particle Size Data
Sintering					
Windbox	kg/Mg (lb/ton) finished sinter				
Uncontrolled					
Leaving grate		5.56	(11.1)	В	Yes
After coarse particulate removal		4.35	(8.7)	Α	
Controlled by dry ESP		0.8	(1.6)	В	
Controlled by wet ESP		0.085	(0.17)	В	Yes
Controlled by venturi scrubber		0.235	(0.47)	В	Yes
Controlled by cyclone		0.5	(1.0)	В	Yes
Sinter discharge (breaker and hot screens)	kg/Mg (lb/ton) finished sinter				
Uncontrolled		3.4	(6.8)	В	
Controlled by baghouse		0.05	(0.1)	В	Yes
Controlled by venturi scrubber		0.295	(0.59)	А	
Windbox and discharge	kg/Mg (lb/ton) finished sinter				
Controlled by baghouse		0.15	(0.3)	Α	

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				••••••••••••••••••••••••••••••••••••••	
Source	Units	Emission Factor		EMISSION FACTOR RATING	Particle Size Data
Blast furnace				· · · · · · · · · · · · · · · · · · ·	
Slip	kg/Mg (lb/ton) slip	39.5	(87.0)	D	
Uncontrolled casthouse	kg/Mg (lb/ton) hot metal			'	
Roof monitor ^b		0.3	(0.6)	В	Yes
Furnace with local evacuation ^c		0.65	(1.3)	B	Yes
Taphole and trough only (not runners)		0.15	(0.3)	В	!
Hot metal desulfurization	kg/Mg (lb/ton) hot metal				
Uncontrolled ^d		0.55	(1.09)	D	Yes
Controlled by baghouse		0.0045	(0.009)	Ď	Yes
Basic oxygen furnace (BOF)			l		ļ
Top blown furnace melting and refining	kg/Mg (lb/ton) steel		I		
Uncontrolled		14.25	(28.5)	В	
Controlled by open hood venter to:					
ESP		0.065	(0.13)	A	
Scrubber		0.045	(0.09)	В	

Table 12.5-1 (cont.).

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Table 12.5-1 (cont.).

Source	Units	Emission Factor		EMISSION FACTOR RATING	Particle Size Data
Controlled by closed hood vented to:					
Scrubber		0.0034	(0.0068)	А	Yes
BOF Charging	kg/Mg (lb/ton) hot metal				
At source		0.3	(0.6)	D	Yes
At building monitor		0.071	(0.142)	В	
Controlled by baghouse		0.0003	(0.0006)	В	Yes
BOF Tapping	kg/Mg (lb/ton) steel				
At source		0.46	(0.92)	D	Yes
At building monitor		0.145	(0.29)	В	
Controlled by baghouse		0.0013	(0.0026)	В	Yes
Hot metal transfer	kg/Mg (lb/ton) hot metal				
At source		0.095	(0.19)	A	
At building monitor		0.028	(0.056)	В	
BOF monitor (all sources)	kg/Mg (lb/ton) steel	0.25	(0.5)	В	
Q-BOF melting and refining	kg/Mg (lb/ton) steel				
Controlled by scrubber		0.028	(0.056)	В	Yes

Source	Units	Emissic	Emission Factor		Particle Size Data
Electric arc furnace					
Melting and refining	kg/Mg (lb/ton) steel				
Uncontrolled carbon steel		19.0	(38.0)	С	Yes
Charging, tapping, and slagging	kg/Mg (lb/ton) steel				
Uncontrolled emissions escaping monitor		0.7	(1.4)	С	
Melting, refining, charging, tapping, and slagging	kg/Mg (lb/ton) steel				
Uncontrolled					
Alloy steel		5.65	(11.3)	A	
Carbon steel		25.0	(50.0)	C	
Controlled by: ^e					
Building evacuation to baghouse for alloy steel		0.15	(0.3)	A	
Direct shell evacuation (plus charging hood) vented to common baghouse for carbon steel		0.0215	(0.043)	E	Yes

Table 12.5-1 (cont.).
Table 12.5-1 (cont.).

Source	Units	Emission Factor		EMISSION FACTOR RATING	Particle Size Data
Open hearth furnace					
Melting and refining	kg/Mg (lb/ton) steel				
Uncontrolled		10.55	(21.1)	D	Yes
Controlled by ESP		0.14	(0.28)	D	Yes
Roof monitor		0.084	(0.168)	С	
Teeming					
Leaded steel	kg/Mg (lb/ton) steel				
Uncontrolled (measured at source)		0.405	(0.81)	A	
Controlled by side draft hood vented to baghouse		0.0019	(0.0038)	A	
Unleaded steel					
Uncontrolled (measured at source)		0.035	(0.07)	Α	
Controlled by side draft hood vented to baghouse		0.0008	(0.0016)	A	
Machine scarfing	kg/Mg (lb/ton) metal through scarfer				
Uncontrolled		0.05	(0.1)	В	
Controlled by ESP		0.0115	(0.023)	A	

Source	Units	Emissio	n Factor	EMISSION FACTOR RATING	Particle Size Data
Miscellaneous combustion sources ^f		f	1		
Boiler, soaking pit, and slab reheat	kg/10 ⁹ J (lb/10 ⁶ Btu)				
Blast furnace gas ^g		0.015	(0.035)	D	
Coke oven gas ^g		0.0052	(0.012)	D	

^a Reference 3, except as noted.
 ^b Typical of older furnaces with no controls, or for canopy hoods or total casthouse evacuation.
 ^c Typical of large, new furnaces with local hoods and covered evacuated runners. Emissions are higher than without capture systems

^d Emission factor of 0.55 kg/Mg (1.09 lb/ton) represents 1 torpedo car; 1.26 kg/Mg (2.53 lb/ton) for 2 torpedo cars, and 1.37 kg/Mg (2.74 lb/ton) for 3 torpedo cars.

 ^e Building evacuation collects all process emissions, and direct shell evacuation collects only melting and refining emissions.
 ^f For various fuels, use the emission factors in Chapter 1 of this document. The EMISSION FACTOR RATING for these fuels in boilers is A, and in soaking pits and slab reheat furnaces is D.

^g Based on methane content and cleaned particulate loading.

	EMISSION	Particle	Cumulative	Cumulati Emission	ive Mass n Factor
Source	RATING	$(\mu m)^a$	Stated Size	kg/Mg	lb/ton
Sintering					
Windbox					
Uncontrolled leaving grate	D	0.5	4 ^b	0.22	0.44
		1.0	4	0.22	0.44
		2.5	65	0.28	0.56
		5.0	9	0.50	1.00
		10	15	0.83	1.67
		15	20 ^c	1.11	2.22
		d	100	5.56	11.1
Controlled by wet ESP	с	0.5	18 ^b	0.015	0.0 3
		1.0	25	0.021	0.04
		2.5	33	0.028	0.06
		5.0	48	0.041	0.08
		10	59 ^b	0.050	0.10
		15	69	0.059	0.12
		d	100	0.085	0.17
Controlled by venturi scrubber	С	0.5	55	0.129	0.26
		1.0	75	0.176	0.35
		2.5	89	0.209	0.42
		5.0	93	0.219	0.44
		10	96	0.226	0.45
		15	98	0.230	0.46
		d	100	0.235	0.47
Controlled by cyclone ^e	с	0.5	25 ^c	0.13	0.25
		1.0	37 ^b	0.19	0.37
		2.5	52	0.26	0.52
		5.0	64	0.32	0.64
		10	74	0.37	0.74
		15	80	0.40	0.80
		d	100	0.5	1.0

Table 12.5-2 (Metric And English Units). SIZE SPECIFIC EMISSION FACTORS

Table 12.5-2 (cont.).

	EMISSION	Particle	Cumulative	Cumulat Emissio	ive Mass n Factor
Source	FACTOR RATING	Size (µm) ^a	Mass $\% \leq$ Stated Size	kg/Mg	lb/ton
Controlled by baghouse	С	0.5	3.0	0.005	0.009
		1.0	9.0	0.014	0.027
		2.5	27.0	0.041	0.081
		5.0	47.0	0.071	0.141
		10.0	69 .0	0.104	0.207
		15.0	79.0	0.119	0.237
		d	100.0	0.15	Ó.3
Sinter discharge breaker and hot	0	0.5	ъb	0.001	0.002
screens controlled by bagnouse	Ľ	0.5	2	0.001	0.002
		1.0	4	0.002	0.004
		2.5	11	0.000	0.011
		5.0	20 22b	0.010	0.020
		10	32 42b	0.010	0.032
		15 d	42	0.021	0.042
			100	0.05	0.1
Blast furnace					
Uncontrolled casthouse emissions			-		
Roof monitor ^f	С	0.5	4	0.01	0.02
		1.0	15	0.05	0.09
		2.5	23	0.07	0.14
		5.0	35	0.11	0.21
		10	51	0.15	0.31
		15	61	0.18	0.37
		d	100	0.3	0.06

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Table 12.5-2 (cont.).

	EMISSION	Particle	Cumulative	Cumulat Emissio	ive Mass n Factor
Source	RATING	Size (µm) ^a	Mass % < Stated Size	kg/Mg	lb/ton
Furnace with local evacuation ^g	С	0.5	7°	0.04	0.09
		1.0	9	0.06	0.12
		2.5	15	0.10	0.20
		5.0	20	0.13	0.26
		10	24	0.16	0.31
		15	26	0.17	0.34
		d	100	0.65	1.3
Hot metal desulfurization ^h					
Uncontrolled	Е	0.5	i		
		1.0	2 ^c	0.01	0.02
		2.5	11	0.06	0.12
		5.0	19	0.10	0.22
		10	19	0.10	0.22
		15	21	0.12	0.23
		d	100	0.55	1.09
Hot metal desulfurization ^h					
Controlled haghouse	D	0.5	8	0.0004	0.0007
	_	1.0	18	0.0009	0.0016
		2.5	42	0.0019	0.0038
		5.0	62	0.0028	0.0056
		10	74	0.0033	0.0067
		15	78	0.0035	0.0070
		d	100	0.0045	0.009

Table 12.5-2 (cont.).

	EMISSION	Particle	Cumulative	Cumulat Emissio	ive Mass n Factor
Source	RATING	Size (µm) ^a	Mass $\% \leq$ Stated Size	kg/Mg	lb/ton
Basic oxygen furnace BOF			_		
Top blown furnace melting and					
refining controlled by closed hood and vented to scrubber	С	0.5	34	0.0012	0.0023
		1.0	55	0.0019	0.0037
		2.5	65	0.0022	0.0044
		5.0	66	0.0022	0.0045
		10	67	0.0023	0.0046
		15	72°	0.0024	0.0049
		d	100	0.0034	0.0068
BOF charging at source ^k	Е	0.5	8 ^c	0.02	0.05
		1.0	12	0.04	0.07
		2.5	22	0.07	0.13
		5.0	35	0.10	0.21
		10	46	0.14	0.28
		15	56	0.17	0.34
		d	100	0.3	0.6
Controlled by baghouse	D	0.5	3	9.0x10 ⁻⁶	1.8x10 ⁻⁵
		1.0	10	3.0x10 ⁻⁵	6.0x10 ⁻⁵
		2.5	22	6.6x10 ⁻⁵	0.0001
		5.0	31	9.3x10 ⁻⁵	0.0002
		10	45	0.0001	0.0003
		15	60	0.0002	0.0004
		d	100	0.0003	0.0006

Table 12.5-2 (cont.).

	EMISSION	Particle	Cumulative	Cumulat Emissio	ive Mass n Factor
Source	RATING	$(\mu m)^{a}$	Mass $\% \leq$ Stated Size	kg/Mg	lb/ton
BOF tapping at source ^k	E	0.5	j	j.	j
		1.0	11	0.05	0.10
		2.5	37	0.17	0.34
		5.0	43	0.20	0.40
		10	45	0.21	0.41
		15	50	0.23	0.46
		d	100	0.46	0.92
BOF tapping					
Controlled by baghouse	D	0.5	4	5.2x10 ⁻⁵	0.0001
		1.0	7	0.0001	0.0002
		2.5	16	0.0002	0.0004
		5.0	22	0.0003	0.0006
		10	30	0.0004	0.0008
		15	40	0.0005	0.0010
		_d	100	0.0013	0.0026
Q-BOP melting and refining	Þ	0.5	15	0.010	0.005
controlled by scrubber	D	0.5	45	0.013	0.025
		1.0	52	0.015	0.029
		2.5	56	0.016	0.031
		5.0	58	0.016	0.032
		10	68	0.019	0.038
		15	85°	0.024	0.048
		^d	100	0.028	0.056

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Table 12.5-2 (cont.).

	EMISSION	Particle	Cumulative	Cumula Emissio	tive Mass on Factor
Source	RATING	Size (µm) ^a	Mass $\% \leq$ Stated Size	kg/Mg	lb/ton
Electric arc furnace melting and refining carbon steel					
Uncontrolled ^m	D	0.5	8	1.52	3.04
		1.0	23	4.37	8.74
		2.5	43	8.17	16.34
		5.0	53	10.07	20.14
		10	58	11.02	22.04
		15	61	11.59	23.18
		d	100	19.0	38.0
Electric arc furnace					
Melting, refining, charging, tapping, slagging					
Controlled by direct shell evacuation plus charing hood					
for carbon steel ⁿ	Е	0.5	74 ^b	0.0159	0.0318
		1.0	74	0.0159	0.0318
		2.5	74	0.0159	0.0318
		5.0	74	0.0159	0.0318
		10	76	0.0163	0.0327
		15	80	0.0172	0.0344
		d	100	0.0215	0.043
Open hearth furnace					
Melting and refining					
Uncontrolled	Е	0.5	1 ^b	0.11	0.21
		1.0	21	2.22	4.43
		2.5	60	6.33	12.66
		5.0	79	8.33	16.67
		10	83	8.76	17.51
		15	•85°	8.97	17.94
		d	100	10.55	21.1

Table 12.5-2 (cont.).

	EMISSION	Particle	Cumulative	mulative Emission	
Source	FACTOR RATING	Size (µm) ^a	Mass $\% \leq$ Stated Size	kg/Mg	lb/ton
Open hearth furnaces					
Controlled by ESP ^p	Е	0.5	10 ^b	0.01	0.02
		1.0	21	0.03	0.06
		2.5	39	0.05	0.10
		5.0	47	0.07	0.13
		10	53 ^b	0.07	0.15
		15	56 ^b	0.08	0.16
		_d	100	0.14	0.28

^a Particle aerodynamic diameter micrometers (μ m) as defined by Task Group on Lung Dynamics. (Particle density = 1 g/cm³).

- ^b Interpolated data used to develop size distribution.
- ^c Extrapolated, using engineering estimates.
- ^d Total particulate based on Method 5 total catch. See Table 12.5-1.
- ^e Average of various cyclone efficiencies.
- ^f Total casthouse evacuation control system.
- ^g Evacuation runner covers and local hood over taphole, typical of new state-of-the-art blast furnace technology.
- ^h Torpedo ladel desulfurization with CaC_2 and $CaCO_3$.
- ^j Unable to extrapolate because of insufficient data and/or curve exceeding limits.
- ^k Doghouse-type furnace enclosure using front and back sliding doors, totally enclosing the furnace, with emissions vented to hoods.
- ^m Full cycle emissions captured by canopy and side draft hoods.
- ⁿ Information on control system not available.
- ^p May not be representative. Test outlet size distribution was larger than inlet and may indicate reentrainment problem.

Table 12.5-3 (Metric And English Units).UNCONTROLLED CARBON MONOXIDEEMISSION FACTORS FOR IRON AND STEEL MILLS^a

EMISSION FACTOR RATING: C

Source	kg/Mg	lb/ton
Sintering windbox ^b	22	44
Basic oxygen furnace ^c	69	138
Electric arc furnace ^c	9	18

^a Reference 6.

^b kg/Mg (lb/ton) of finished sinter.

^c kg/Mg (lb/ton) of finished steel.



Figure 12.5-2. Particle size distribution of sinter plant emissions.



Figure 12.5-3. Particle size distribution of basic oxygen furnace emissions.

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SOURCE CATEGORY/CONTROLS

BLAST FURNACE CASTHOUSE/UNCONTROLLED Total Building Evacuation	
BLAST FURNACE CASTHOUSE/UNCONTROLLED Local Hood & Runner Evacuation System	
OPEN HEARTH/UNCONTROLLED	
OPEN HEARTH / ESP	
ELECTRIC AND FURNACE / UNCONTROLLED	· <i>•</i> -
ELECTRIC AND FURNACE / BAGHOUSE	•• <i>-</i>
HOT METAL DESULFURIZATION /UNCONTROLLED	····· • ·····
HOT METAL DESULFURIZATION/BAGHOUSE	

EXTRAPOLATED BY EXTENDING THE CURVES ON THE GRAPH



Dynamics definition of Aerodynamic Diameter)

Figure 12.5-4. Particle size distribution of blast furnace, open hearth, electric arc furnace and hot metal desulfurization emissions.

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Table 12.5-4 (Metric And English Units). UNCONTROLLED PARTICULATE EMISSION FACTORS FOR OPEN DUST SOURCES AT IRON AND STEEL MILLS^a

	Emissions By Particle Size Range (Aerodynamic Diameter)						EMISSION
Operation	≤ 30 µm	≤ 15 µm	≤ 10 µm	≤ 5 μm	≤ 2.5 µm	Units ^b	RATING
Continuous Drop Conveyor transfer station sinter ^c	13 0.026	9.0 0.018	6.5 0.013	4.2 0.0084	2.3 0.0046	g/Mg lb/ton	D D
Pile formation stacker pellet ore ^c	1.2 0.0024	0.75 0.0015	0.55 0.0011	0.32 0.00064	0.17 0.00034	g/Mg lb/ton	B B
Lump ore ^c	0.15 0.00030	0.095 0.00019 <u></u>	0.075 0.00015	0.040 0.000081	0.022 0.000043	g/Mg lb/ton	C C
Coald	0.055 0.00011	0.034 0.000068	0.026 0.000052	0.014 0.000028	0.0075 0.000015	g/Mg lb/ton	E E
Batch drop Front end loader/truck ^c							
High silt slag	13 0.026	8.5 0.017	6.5 0.013	4.0 0.0080	2.3 0.0046	g/Mg lb/ton	C C
Low silt slag	4.4 0.0088	2.9 0.0058	2.2 0.0043	1.4 0.0028	0.8 0.0016	g/Mg lb/ton	с с
Vehicle travel on unpaved roads Light duty						kg/VKT lb/VMT	C C
vehicled	0.51 1.8	0.37 1.3	0.28 1.0	0.18 0.64	0.10 0.36		
Medium duty vehicle ^d	2.1 7.3	1.5 5.2	1.2 4.1	0.70 2.5	0.42 1.5	kg/VKT lb/VMT	C C
Heavy duty vehicle ^d	3.9 14	2.7 9. 7	2.1 7.6	1.4 4.8	0.76 2.7	kg/VKT lb/VMT	B B
Vehicle travel on paved roads Light/heavy							C C
vehicle mix ^c	0.22 0.78	0.16 0.58	0.12 0.44	0.079 0.28	0.042 0.15	kg/VKT lb/VMT	

^a Predictive emission factor equations are generally preferred over these single values emission factors. Predictive emission factor estimates are presented in Chapter 13, Section 13.2.

VKT = Vehicle kilometers traveled. VMT = Vehicle miles traveled.

^b Units/unit of material transferred or units/unit of distance traveled.

^c Reference 4. Interpolation to other particle sizes will be approximate.

^d Reference 5. Interpolation to other particle sizes will be approximate.

EMISSION FACTORS

References For Section 12.5

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12.6 Primary Lead Smelting

12.6.1 General¹⁵

Lead is found naturally as a sulfide ore containing small amounts of copper, iron, zinc, precious metals, and other trace elements. The lead in this ore, typically after being concentrated at or near the mine (see Section 12.18), is processed into metallurgical lead at 4 facilities in the U. S. (2 smelters/refineries in Missouri, 1 smelter in Montana, and 1 refinery in Nebraska). Demand for lead from these primary sources is expected to remain relatively stable in the early 1990s, due in large part to storage battery recycling programs being implemented by several states. Significant emissions of sulfur dioxide (SO₂), particulate matter, and especially lead have caused much attention to be focused on identifying, and quantifying emissions from, sources within these facilities.

12.6.2 Process Description^{15,16}

The processing of lead concentrate into metallurgical lead involves 3 major steps: sintering, reduction, and refining. A diagram of a typical facility, with particle and gaseous emission sources indicated, is shown in Figure 12.6-1.

12.6.2.1 Sintering -

The primary purpose of the sinter machine is the reduction of sulfur content of the feed material. This feed material typically consists of the following:

- 1. Lead concentrates, including pyrite concentrates that are high in sulfur content, and concentrates that are high in impurities such as arsenic, antimony, and bismuth, as well as relatively pure high-lead-concentrates;
- 2. Lime rock and silica, incorporated in the feed to maintain a desired sulfur content;
- 3. High-lead-content sludge byproducts from other facilities; and
- 4. Undersized sinter recycled from the roast exiting the sinter machine.

The undersized sinter return stream mixes with the other feed components, or green feed, as the 2 streams enter a rotary pelletizing drum. A water spray into the drum enhances the formation of nodules in which the sinter returns form a core rich in lead oxide and the green feed forms a coating rich in lead sulfide. The smaller nodules are separated out and conveyed through an ignition furnace, then covered with the remaining nodules on a moving grate and conveyed through the sinter machine, which is essentially a large oven. Excess air is forced upward through the grate, facilitating combustion, releasing SO₂ and oxidizing the lead sulfide to lead oxide. The "strong gas" from the front end of the sinter machine, containing 2.5 to 4 percent SO₂, is vented to gas cleaning equipment before possibly being piped to a sulfuric plant. Gases from the rear part of the sinter machine are recirculated up through the moving grate and are typically vented to a baghouse. That portion of the product which is undersized, usually due to insufficient desulfurization, is filtered out and recycled through the sinter; the remaining sinter roast is crushed before being transported to the blast furnace.



Figure 12.6-1. A typical primary lead smelting and refining. (Source Classification Code in parentheses.)

12.6.2.2 Reduction -

The sinter roast is then conveyed to the blast furnace in charge cars along with coke, ores containing high amounts of precious metals, slags and byproducts dusts from other smelters, and byproduct dusts from baghouses and various other sources within the facility. Iron scrap is often added to the charge to aid heat distribution and to combine with the arsenic in the charge. The blast furnace process rate is controlled by the proportion of coke in the charge and by the air flow through the tuyeres in the floor of the furnace. The charge descends through the furnace shaft into the smelting zone, where it becomes molten, and is tapped into a series of settlers that allow the separation of lead from slag. The slag is allowed to cool before being stored, and the molten lead of roughly 85 percent purity is transported in pots to the dross building.

12.6.2.3 Refining -

The drossing area consists of a variety of interconnected kettles, heated from below by natural gas combustion. The lead pots arriving from the blast furnace are poured into receiving kettles and allowed to cool to the point at which copper dross rises to the top of the top and can be skimmed off and transferred to a reverbatory furnace. The remaining lead dross is transferred to a finishing kettle where such materials as wood chips, coke fines, and sulfur are added and mixed to facilitate further separation, and this sulfur dross is also skimmed off and transferred to the reverbatory furnace. To the drosses in the reverbatory furnace are added tetrahedrite ore, which is high in silver content but low in lead and may have been dried elsewhere within the facility, coke fines, and soda ash. When heated in the same fashion as the kettles, the dross in the reverbatory furnace separates into 3 layers: lead bullion settles to the bottom and is tapped back to the receiving kettles, and matte (copper sulfide and other metal sulfides), which rises to the top, and speiss (high in arsenic and antimony content) are both typically forwarded to copper smelters.

The third and final phase in the processing of lead ore to metallurgical lead, the refining of the bullion in cast iron kettles, occurs in 5 steps: (1) removal of antimony, tin, and arsenic; (2) removal of precious metals by Parke's Process, in which zinc combines with gold and silver to form an insoluble intermetallic at operating temperatures; (3) vacuum removal of zinc; (4) removal of bismuth by the Betterson Process, in which calcium and magnesium are added to form an insoluble compound with the bismuth that is skimmed from the kettle; and (5) removal of remaining traces of metal impurities through the adding of NaOH and NaNO₃. The final refined lead, from 99.990 to 99.999 percent pure, is typically cast into 45 kilogram (100 pound) pigs for shipment.

12.6.3 Emissions And Controls¹⁵⁻¹⁷

Emissions of lead and particulate occur in varying amounts from nearly every process and process component within primary lead smelter/refineries, and SO_2 is also emitted from several sources. The lead and particulate emissions point, volume, and area sources may include:

- 1. The milling, dividing, and fire assaying of samples of incoming concentrates and high-grade ores;
- 2. Fugitive emissions within the crushing mill area, including the loading and unloading of ores and concentrates from rail cars onto conveyors;
- 3. The ore crushers and associated transfer points, which may be controlled by baghouses;

- 4. Fugitive emissions from the unloading, storage, and transfer of byproduct dusts, highgrade ores, residues, coke, lime, silica, and any other materials stored in outdoor piles;
- 5. Strong gases from the front end of the sinter machine, which are typically vented to an electrostatic precipitator (ESP), 1 or more scrubbers, and a wet ESP for sulfuric acid mist elimination, but during shutdowns of the acid plant may bypass the ESP;
- 6. Weak gases from the back end of the sinter machine, which are high in lead dust content but typically pass through cyclones and a baghouse;
- 7. Fugitive emissions from the sinter building, including leaks in the sinter machine and the sinter cake crusher;
- 8. Gases exiting the top of the blast furnace, which are typically controlled with a baghouse;
- 9. Fugitive emissions from the blast furnace, including leaks from the furnace covers and the bottoms of charge cars, dust from the charge car bottom dump during normal operation, and escaping gases when blow holes develop in the shaft and must be "shot" with explosives;
- 10. Lead fumes from the molten lead and slag leaving the blast furnace area;
- 11. Fugitive leaks from the tapping of the kettles and settlers;
- 12. The hauling and dumping of slag, at both the handling and cooling area and the slag storage pile;
- 13. The combustion of natural gas, as well as the creation of lead-containing fumes at the kettles and reverbatory furnace, all of which are typically vented to a baghouse at the drossing building;
- 14. Fugitive emissions from the various pouring, pumping, skimming, cooling, and tapping operations within the drossing building;
- 15. The transporting, breaking, granulating, and storage of speiss and matte;
- 16. The loading, transferring, and drying of tetrahedrite ore, which is typically controlled with cyclones and a baghouse;
- 17. The periodic cleanout of the blast and reverbatory furnaces; and
- 18. Dust caused by wind erosion and plant vehicular traffic, which are normally estimated with factors from Section 13.2 of AP-42, but are addressed herein due to the high lead content of the dust at primary lead smelting and refining facilities.

Tables 12.6.1 and 12.6.2 present particulate, PM-10, lead, and SO_2 emission factors for primary lead smelting.

Process	Particulate ^b	PM-10°	Lead	SO ₂
Ore crushing ^d (SCC 3-03-010-04)	0.023	0.018	0.001	NA
Ore screening ^e (SCC 3-03-010-27)	0.004	0.005	0.001	NA
Tetrahedrite drier ^f (SCC 3-03-010-28)	0.012	0.013	0.0003	NA
Sinter machine (weak gas) ^g (SCC 3-03-010-29)	0.051	0.052	0.009	275 ^h
Sinter building fugitives ^g (SCC 3-03-010-25)	0.118	0.058	0.016	NA
Sinter storage ^j (SCC 3-03-010-30)	NA	NA	NA	NA
Blast furnace ^k (SCC 3-03-010-02)	0.21	0.43	0.034	23 ^h
Speiss pit ^m (SCC 3-03-010-31)	NA	NA	NA	NA

EMISSION FACTOR RATING: E

^a Most of the processes are controlled by baghouses; otherwise it is noted. SCC = Source Classification Code. NA = not applicable.

^b Filterable particulate only. ^c Filterable and condensable particulate; $\leq 10 \,\mu$ m mean diameter.

^d Entire ore crushing building at one facility, including transfer points; kg/Mg of ore, except lead, which is kg/Mg of lead in ore.

^e Tests at one facility; kg/Mg ore.

^f kg/Mg dried; tests at one facility.

^g kg/Mg sinter produced; tests at one facility. The sinter machine is controlled by ESP and scrubbers.

^h Uncontrolled emission factor from 1971 tests on two facilities (References 5 and 6).

^j kg/Mg throughput; includes charge car loading; from tests at one facility.

^k kg/Mg of bullion, includes dross kettles; from tests at one facility.

m kg/Mg granulated; from tests at one facility.

Table 12.6-2 (English Units). EMISSION FACTORS FOR PRIMARY LEAD SMELTING^a

Process	Particulate ^b	PM-10 ^c	Lead	so ₂
Ore crushing ^d (SCC 3-03-010-04)	0.0445	0.036	0.002	NA
Ore screening ^e (SCC 3-03-010-27)	0.007	0.009	0.002	NA
Tetrahedrite drier ^f (SCC 3-03-010-28)	0.023	0.026	0.0006	NA
Sinter machine (weak gas) ^g (SCC 3-03-010-29)	0.10	0.104	0.019	550 ^h
Sinter building fugitives ^g (SCC 3-03-010-25)	0.24	0.117	0.032	NA
Sinter storage ^j (SCC 3-03-010-30)	NA	NA	NA	NA
Blast furnace ^k (SCC 3-03-010-02)	0.43	0.863	0.067	45 ^h
Speiss pit ^m (SCC 3-03-101-31)	NA	NA	NA	NA

EMISSION FACTOR RATING: E

^c Filterable and condensable particulate; $\leq 10 \ \mu m$ mean diameter. ^d Entire ore crushing building at one facility, including transfer points; lb/ton of ore, except lead, which is lb/ton of lead in ore.

^e Tests at one facility; lb/ton ore. ^f lb/ton dried; tests at one facility.

^g lb/ton sinter produced; tests at one facility. The sinter machine is controlled by ESP and scrubbers. ^h Uncontrolled emission factor from 1971 tests on two facilities (5,6).

^j lb/ton throughput; includes charge car loading; from tests at one facility.

^k lb/ton of bullion, includes dross kettles; from tests at one facility.

^m lb/ton granulated; from tests at one facility.

References For Section 12.6

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12.7 Zinc Smelting

12.7.1 General¹⁻²

Zinc is found in the earth's crust primarily as zinc sulfide (ZnS). Primary uses for zinc include galvanizing of all forms of steel, as a constituent of brass, for electrical conductors, vulcanization of rubber and in primers and paints. Most of these applications are highly dependent upon zinc's resistance to corrosion and its light weight characteristics. In 1991, approximately 260,000 megagrams (287,000 tons) of zinc were refined at the 4 U. S. primary zinc smelters. The annual production volume has remained constant since the 1980s. Three of these 4 plants, located in Illinois, Oklahoma, and Tennessee, utilize electrolytic technology, and the 1 plant in Pennsylvania uses an electrothermic process. This annual production level approximately equals production capacity, despite a mined zinc ore recovery level of 520 megagrams (573 tons), a domestic zinc demand of 1190 megagrams (1311 tons), and a secondary smelting production level of only 110 megagrams (121 tons). As a result, the U. S. is a leading exporter of zinc concentrates as well as the world's largest importer of refined zinc.

Zinc ores typically may contain from 3 to 11 percent zinc, along with cadmium, copper, lead, silver, and iron. Beneficiation, or the concentration of the zinc in the recovered ore, is accomplished at or near the mine by crushing, grinding, and flotation process. Once concentrated, the zinc ore is transferred to smelters for the production of zinc or zinc oxide. The primary product of most zinc companies is slab zinc, which is produced in 5 grades: special high grade, high grade, intermediate, brass special, and prime western. The 4 U. S. primary smelters also produce sulfuric acid as a byproduct.

12.7.2 Process Description

Reduction of zinc sulfide concentrates to metallic zinc is accomplished through either electrolytic deposition from a sulfate solution or by distillation in retorts or furnaces. Both of these methods begin with the elimination of most of the sulfur in the concentrate through a roasting process, which is described below. A generalized process diagram depicting primary zinc smelting is presented in Figure 12.7-1.

Roasting is a high-temperature process that converts zinc sulfide concentrate to an impure zinc oxide called calcine. Roaster types include multiple-hearth, suspension, or fluidized bed. The following reactions occur during roasting:

$$2ZnS + 3O_2 \rightarrow 2ZnO + SO_2 \tag{1}$$

$$2SO_2 + O_2 \rightarrow 2SO_3 \tag{2}$$

In a multiple-hearth roaster, the concentrate drops through a series of 9 or more hearths stacked inside a brick-lined cylindrical column. As the feed concentrate drops through the furnace, it is first dried by the hot gases passing through the hearths and then oxidized to produce calcine. The reactions are slow and can be sustained only by the addition of fuel. Multiple hearth roasters are unpressurized and operate at about 690°C (1300°F). Operating time depends upon the composition of concentrate and the amount of the sulfur removal required. Multiple hearth roasters have the capability of producing a high-purity calcine.





In a suspension roaster, the concentrates are blown into a combustion chamber very similar to that of a pulverized coal furnace. The roaster consists of a refractory-lined cylindrical steel shell, with a large combustion space at the top and 2 to 4 hearths in the lower portion, similar to those of a multiple hearth furnace. Additional grinding, beyond that required for a multiple hearth furnace, is normally required to ensure that heat transfer to the material is sufficiently rapid for the desulfurization and oxidation reactions to occur in the furnace chamber. Suspension roasters are unpressurized and operate at about $980^{\circ}C$ ($1800^{\circ}F$).

In a fluidized-bed roaster, finely ground sulfide concentrates are suspended and oxidized in a feedstock bed supported on an air column. As in the suspension roaster, the reaction rates for desulfurization are more rapid than in the older multiple-hearth processes. Fluidized-bed roasters operate under a pressure slightly lower than atmospheric and at temperatures averaging 1000°C (1800°F). In the fluidized-bed process, no additional fuel is required after ignition has been achieved. The major advantages of this roaster are greater throughput capacities and greater sulfur removal capabilities.

Electrolytic processing of desulfurized calcine consists of 3 basic steps, leaching, purification, and electrolysis. Leaching occurs in an aqueous solution of sulfuric acid, yielding a zinc sulfate solution as shown in Equation 3 below.

$$ZnO + SO_3 \rightarrow ZnSO_4$$
 (3)

In double leaching, the calcine is first leached in a neutral or slightly alkaline solution, then in an acidic solution, with the liquid passing countercurrent to the flow of calcine. In the neutral leaching solution, sulfates from the calcine dissolve, but only a portion of the zinc oxide enters into solution. The acidic leaching solution dissolves the remainder of the zinc oxide, along with metallic impurities such as arsenic, antimony, cobalt, germanium, nickel, and thallium. Insoluble zinc ferrite, formed during concentrate roasting by the reaction of iron with zinc, remains in the leach residue, along with lead and silver. Lead and silver typically are shipped to a lead smelter for recovery, while the zinc is extracted from the zinc ferrite to increase recovery efficiency.

In the purification process, a number of various reagents are added to the zinc-laden electrolyte in a sequence of steps designed to precipitate the metallic impurities, which otherwise will interfere with deposition of zinc. After purification, concentrations of these impurities are limited to less than 0.05 milligram per liter (4×10^{-7} pounds per gallon). Purification is usually conducted in large agitated tanks. The process takes place at temperatures ranging from 40 to 85°C (104 to 185°F), and pressures ranging from atmospheric to 240 kilopascals (kPa) (2.4 atmospheres).

In electrolysis, metallic zinc is recovered from the purified solution by passing current through an electrolyte solution, causing zinc to deposit on an aluminum cathode. As the electrolyte is slowly circulated through the cells, water in the electrolyte dissociates, releasing oxygen gas at the anode. Zinc metal is deposited at the cathode and sulfuric acid is regenerated for recycle to the leach process. The sulfuric acid acts as a catalyst in the process as a whole.

Electrolytic zinc smelters contain as many as several hundred cells. A portion of the electrical energy is converted into heat, which increases the temperature of the electrolyte. Electrolytic cells operate at temperature ranges from 30 to 35°C (86 to 95°F) and at atmospheric pressure. A portion of the electrolyte is continuously circulated through the cooling towers both to cool and concentrate the electrolyte through evaporation of water. The cooled and concentrated electrolyte is then recycled to the cells. Every 24 to 48 hours, each cell is shut down, the zinc-coated cathodes are removed and rinsed, and the zinc is mechanically stripped from the aluminum plates.

The electrothermic distillation retort process, as it exists at 1 U. S. plant, was developed by the St. Joe Minerals Corporation in 1930. The principal advantage of this pyrometallurgical technique over electrolytic processes is its ability to accommodate a wide variety of zinc-bearing materials, including secondary items such as calcine derived from electric arc furnace (EAF) dust. Electrothermic processing of desulfurized calcine begins with a downdraft sintering operation, in which grate pallets are joined to form a continuous conveyor system. The sinter feed is essentially a mixture of roaster calcine and EAF calcine. Combustion air is drawn down through the conveyor, and impurities such as lead, cadmium, and halides in the sinter feed are driven off and collected in a bag filter. The product sinter typically includes 48 percent zinc, 8 percent iron, 5 percent aluminum, 4 percent silicon, 2.5 percent calcium, and smaller quantities of magnesium, lead, and other metals.

Electric retorting with its greater thermal efficiency than externally heated furnaces, is the only pyrometallurgical technique utilized by the U. S. primary zinc industry, now and in the future. Product sinter and, possibly, secondary zinc materials are charged with coke to an electric retort furnace. The charge moves downward from a rotary feeder in the furnace top into a refractory-lined vertical cylinder. Paired graphite electrodes protrude from the top and bottom of this cylinder, producing a current flow. The coke serves to provide electrical resistance, producing heat and generating the carbon monoxide required for the reduction process. Temperatures of 1400°C (2600°F) are attained, immediately vaporizing zinc oxides according to the following reaction:

$$ZnO + CO \rightarrow Zn (vapor) + CO_2$$
 (4)

The zinc vapor and carbon dioxide pass to a vacuum condenser, where zinc is recovered by bubbling through a molten zinc bath. Over 95 percent of the zinc vapor leaving the retort is condensed to liquid zinc. The carbon dioxide is regenerated with carbon, and the carbon monoxide is recycled back to the retort furnace.

12.7.3 Emissions And Controls

Each of the 2 smelting processes generates emissions along the various process steps. The roasting process in a zinc smelter is typically responsible for more than 90 percent of the potential SO_2 emissions. About 93 to 97 percent of the sulfur in the feed is emitted as sulfur oxides. Concentrations of SO_2 in the offgas vary with the type of roaster operation. Typical SO_2 concentrations for multiple hearth, suspension, and fluidized bed roasters are 4.5 to 6.5 percent, 10 to 13 percent, and 7 to 12 percent, respectively. Sulfur dioxide emissions from the roasting processes at all 4 U. S. primary zinc processing facilities are recovered at on-site sulfuric acid plants. Much of the particulate matter emitted from primary zinc processing facilities is also attributable to the concentrate roasters. The amount and composition of particulate varies with operating parameters, such as air flow rate and equipment configuration. Various combinations of control devices such as cyclones, electrostatic precipitators (ESP), and baghouses can be used on roasters and on sintering machines, achieving 94 to 99 percent emission reduction.

Controlled and uncontrolled particulate emission factors for points within a zinc smelting facility are presented in Tables 12.7-1 and 12.7-2. Fugitive emission factors are presented in Tables 12.7-3 and 12.7-4. These emission factors should be applied carefully. Emission factors for sintering operations are derived from data from a single facility no longer operating. Others are estimated based on similar operations in the steel, lead, and copper industries. Testing on 1 electrothermic primary zinc smelting facility indicates that cadmium, chromium, lead, mercury, nickel, and zinc are contained in the offgases from both the sintering machine and the retort furnaces.

EMISSION FACTORS

Process	Uncontrolled	EMISSION FACTOR RATING	Controlled	EMISSION FACTOR RATING
Roasting Multiple hearth ^b (SCC 3-03-030-02) Suspension ^c (SCC 3-03-030-07) Fluidized bed ^d (SCC 3-03-030-08)	113 1000 1083	E E E	ND 4 ND	NA E NA
Sinter plant (SCC 3-03-030-03) Uncontrolled ^e With cyclone ^f With cyclone and ESP ^f	62.5 NA NA	E NA NA	NA 24.1 8.25	NA E E
Vertical retort ^g (SCC 3-03-030-05)	7.15	D	ND	NA
Electric retorth (SCC 3-03-030-29)	10.0	Е	ND	NA
Electrolytic process ^j (SCC 3-03-030- 06)	3.3	E	ND	NA

Table 12.7-1 (Metric Units). PARTICULATE EMISSION FACTORS FOR ZINC SMELTING^a

^a Factors are for kg/Mg of zinc ore processed. SCC = Source Classification Code. ESP = Electrostatic precipitator. ND = no data. NA = not applicable.

^b References 5-7. Averaged from an estimated 10% of feed released as particulate, zinc production rate at 60% of roaster feed rate, and other estimates.

- ^c References 5-7. Based on an average 60% of feed released as particulate emission and a zinc production rate at 60% of roaster feed rate. Controlled emissions based on 20% dropout in waste heat boiler and 99.5% dropout in cyclone and ESP.
- ^d References 5,13. Based on an average 65% of feed released as particulate emissions and a zinc production rate of 60% of roaster feed rate.
- e Reference 5. Based on unspecified industrial source data.
- ^f Reference 8. Data not necessarily compatible with uncontrolled emissions.
- ^g Reference 8.
- ^h Reference 14. Based on unspecified industrial source data.
- ^j Reference 10.

Process	Uncontrolled	EMISSION FACTOR RATING	Controlled	EMISSION FACTOR RATING
Roasting				
Multiple hearth ^b (SCC 3-03-030-02)	227	Ε	ND	NA
Suspension ^c (SCC 3-03-030-07)	2000	Ε	8	Е
Fluidized bed ^d (SCC 3-03-030-08)	2167	Ε	ND	NA
Sinter plant (SCC 3-03-030-03)	:			
Uncontrolled ^e	125	Е	NA	NA
With cyclone ^f	NA	NA	48.2	Е
With cyclone and ESP ^f	NA	NA	16.5	Е
Vertical retort ^g (SCC 3-03-030-05)	14.3	D	ND	NA
Electric retorth (SCC 3-03-030-29)	20.0	Е	ND	NA
Electrolytic process ^j (SCC 3-03-030- 06)	6.6	Е	ND	NA

Table 12.7-2 (English Units). PARTICULATE EMISSION FACTORS FOR ZINC SMELTING^a

^a Factors are for lb/ton of zinc ore processed. SCC = Source Classification Code. ESP = Electrostatic precipitator. ND = no data. NA = not applicable.

^b References 5-7. Averaged from an estimated 10% of feed released as particulate, zinc production rate at 60% of roaster feed rate, and other estimates.

^c References 5-7. Based on an average 60% of feed released as particulate emission and a zinc production rate at 60% of roaster feed rate. Controlled emissions based on 20% dropout in waste heat boiler and 99.5% dropout in cyclone and ESP.

^d References 5,13. Based on an average 65% of feed released as particulate emissions and a zinc production rate of 60% of roaster feed rate.

^e Reference 5. Based on unspecified industrial source data.

^f Reference 8. Data not necessarily compatible with uncontrolled emissions.

^g Reference 8.

^h Reference 14. Based on unspecified industrial source data.

^j Reference 10.

Table 12.7-3 (Metric Units). UNCONTROLLED FUGITIVE PARTICULATE EMISSIONFACTORS FOR SLAB ZINC SMELTING^a

Process	Emissions	EMISSION FACTOR RATING
Roasting (SCC 3-03-030-24)	Negligible	NA
Sinter plant ^b Wind box (SCC 3-03-030-25) Discharge screens (SCC 3-03-030-26)	0.12 - 0.55 0.28 - 1.22	E E
Retort building ^c (SCC 3-03-030-27)	1.0 - 2.0	Е
Casting ^d (SCC 3-03-030-28)	1.26	E

^a Reference 9. Factors are in kg/Mg of product. SCC = Source Classification Code. NA = not applicable.

^b From steel industry operations for which there are emission factors. Based on quantity of sinter produced.

^c From lead industry operations.

^d From copper industry operations.

Table 12.7-4 (English Units). UNCONTROLLED FUGITIVE PARTICULATE EMISSION FACTORS FOR SLAB ZINC SMELTING^a

Process	Emissions	EMISSION FACTOR RATING
Roasting (SCC 3-03-030-24)	Negligible	NA
Sinter plant ^b Wind box (SCC 3-03-030-25) Discharge screens (SCC 3-03-030-26)	0.24 - 1.10 0.56 - 2.44	E E
Retort building ^c (SCC 3-03-030-27)	2.0 - 4.0	Е
Casting ^d (SCC 3-03-030-28)	2.52	Е

^a Reference 9. Factors are in lb/ton of product. SCC = Source Classification Code.
 NA = not applicable.

^b From steel industry operations for which there are emission factors. Based on quantity of sinter produced.

^c From lead industry operations.

^d From copper industry operations.

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12.8 Secondary Aluminum Operations

12.8.1 General¹

Secondary aluminum producers recycle aluminum from aluminum-containing scrap, while primary aluminum producers convert bauxite ore into aluminum. The secondary aluminum industry was responsible for 27.5 percent of domestic aluminum produced in 1989. There are approximately 116 plants with a recovery capacity of approximately 2.4 million megagrams (2.6 million tons) of aluminum per year. Actual total secondary aluminum production was relatively constant during the 1980s. However, increased demand for aluminum by the automobile industry has doubled in the last 10 years to an average of 78.5 kilograms (173 pounds) per car. Recycling of used aluminum beverage cans (UBC) increased more than 26 percent from 1986 to 1989. In 1989, 1.3 million megagrams (1.4 million tons) of UBCs were recycled, representing over 60 percent of cans shipped. Recycling a ton of aluminum requires only 5 percent of the energy required to refine a ton of primary aluminum from bauxite ore, making the secondary aluminum economically viable.

12.8.2 Process Description

Secondary aluminum production involves 2 general categories of operations, scrap pretreatment and smelting/refining. Pretreatment operations include sorting, processing, and cleaning scrap. Smelting/refining operations include cleaning, melting, refining, alloying, and pouring of aluminum recovered from scrap. The processes used to convert scrap aluminum to products such as lightweight aluminum alloys for industrial castings are presented in Figure 12.8-1A and Figure 12.8-1B. Some or all the steps in these figures may be involved at any one facility. Some steps may be combined or reordered, depending on scrap quality, source of scrap, auxiliary equipment available, furnace design, and product specifications. Plant configuration, scrap type usage, and product output varies throughout the secondary aluminum industry.

12.8.2.1 Scrap Pretreatment -

Aluminum scrap comes from a variety of sources. "New" scrap is generated by preconsumer sources, such as drilling and machining of aluminum castings, scrap from aluminum fabrication and manufacturing operations, and aluminum bearing residual material (dross) skimmed off molten aluminum during smelting operations. "Old" aluminum scrap is material that has been used by the consumer and discarded. Examples of old scrap include used appliances, aluminum foil, automobile and airplane parts, aluminum siding, and beverage cans.

Scrap pretreatment involves sorting and processing scrap to remove contaminants and to prepare the material for smelting. Sorting and processing separates the aluminum from other metals, dirt, oil, plastics, and paint. Pretreatment cleaning processes are based on mechanical, pyrometallurgical, and hydrometallurgical techniques.

12.8.2.1.1 Mechanical Cleaning -

Mechanical cleaning includes the physical separation of aluminum from other scrap, with hammer mills, ring rushers, and other machines to break scrap containing aluminum into smaller pieces. This improves the efficiency of downstream recovery by magnetic removal of iron. Other recovery processes include vibratory screens and air classifiers.



Figure 12.8-1A. Typical process diagram for secondary aluminum processing industry. (Source Classification Codes in parentheses.)



Figure 12.8-1B. Typical process diagram for secondary aluminum processing industry. (Source Classification Codes in parentheses.)

An example of mechanical cleaning is the dry milling process. Cold aluminum-laden dross and other residues are processed by milling and screening to obtain a product containing at least 60 to 70 percent aluminum. Ball, rod, or hammer mills can be used to reduce oxides and nonmetallic particles to fine powders for ease of removal during screening.

12.8.2.1.2 Pyrometallurgical Cleaning -

Pyrometallurgical techniques (called drying in the industry) use heat to separate aluminum from contaminates and other metals. Pyrometallurgical techniques include roasting and sweating. The roasting process involves heating aluminum scrap that contains organic contaminates in rotary dryers to temperatures high enough to vaporize or carbonize organic contaminates, but not high enough to melt aluminum (660°C [1220°F]). An example of roasting is the APROS delacquering and preheating process used during the processing of used beverage cans (shown in Figure 12.8-2). The sweating process involves heating aluminum scrap containing other metals in a sweat furnace to temperatures above the melting temperature of aluminum, but below that of the other metal. For example, sweating recovers aluminum from high-iron-content scrap by heating the scrap in an open flame reverberatory furnace. The temperature is raised and maintained above the melting temperature of aluminum, but below the melting temperature is raised and maintained above the melting temperature of aluminum, but below the melting temperature of iron. This condition causes aluminum and other low melting constituents to melt and trickle down the sloped hearth, through a grate and into aircooled molds or collecting pots. This product is called "sweated pig". The higher-melting materials, including iron, brass, and the oxidation products formed during the sweating process, are periodically removed from the furnace.

In addition to roasting and sweating, a catalytic technique may also be used to clean aluminum dross. Dross is a layer of impurities and semisolid flux that has been skimmed from the surface of molten aluminum. Aluminum may be recovered from dross by batch fluxing with a salt/cryolite mixture in a mechanically rotated, refractory-lined barrel furnace. Cryolite acts as a catalyst that decreases aluminum surface tension and therefore increases recovery rates. Aluminum is tapped periodically through a hole in the base of the furnace.

12.8.2.1.3 Hydrometallurgical Cleaning -

Hydrometallurgical techniques use water to clean and process aluminum scrap. Hydrometallurgical techniques include leaching and heavy media separation. Leaching is used to recover aluminum from dross, furnace skimmings, and slag. It requires wet milling, screening, drying, and finally magnetic separation to remove fluxing salts and other waste products from the aluminum. First, raw material is fed into a long rotating drum or a wet-ball mill where water soluble contaminants are rinsed into waste water and removed (leached). The remaining washed material is then screened to remove fines and undissolved salts. The screened material is then dried and passed through a magnetic separator to remove ferrous materials.

The heavy media separation hydrometallurgical process separates high density metal from low density metal using a viscous medium, such as copper and iron, from aluminum. Heavy media separation has been used to concentrate aluminum recovered from shredded cars. The cars are shredded after large aluminum components have been removed (shredded material contains approximately 30 percent aluminum) and processed in heavy media to further concentrate aluminum to 80 percent or more.

12.8.2.2 Smelting/Refining -

After scrap pretreatment, smelting and refining is performed. Smelting and refining in secondary aluminum recovery takes place primarily in reverberatory furnaces. These furnaces are brick-lined and constructed with a curved roof. The term reverberatory is used because heat rising



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Figure 12.8-2. APROS delacquering and preheating process.

from ignited fuel is reflected (reverberated) back down from the curved furnace roof and into the melted charge. A typical reverberatory furnace has an enclosed melt area where the flame heat source operates directly above the molten aluminum. The furnace charging well is connected to the melt area by channels through which molten aluminum is pumped from the melt area into the charging well. Aluminum flows back into the melt section of the furnace under gravity.

Most secondary aluminum recovery facilities use batch processing in smelting and refining operations. It is common for 1 large melting reverberatory furnace to support the flow requirements for 2 or more smaller holding furnaces. The melting furnace is used to melt the scrap, and remove impurities and entrained gases. The molten aluminum is then pumped into a holding furnace. Holding furnaces are better suited for final alloying, and for making any additional adjustments necessary to ensure that the aluminum meets product specifications. Pouring takes place from holding furnaces, either into molds or as feedstock for continuous casters.

Smelting and refining operations can involve the following steps: charging, melting, fluxing, demagging, degassing, alloying, skimming, and pouring. Charging consists of placing pretreated aluminum scrap into a melted aluminum pool (heel) that is maintained in melting furnaces. The scrap, mixed with flux material, is normally placed into the furnace charging well, where heat from the molten aluminum surrounding the scrap causes it to melt by conduction. Flux materials combine with contaminates and float to the surface of the aluminum, trapping impurities and providing a barrier (up to 6 inches thick) that reduces oxidation of the melted aluminum. To minimize aluminum oxidation (melt loss), mechanical methods are used to submerge scrap into the heel as quickly as possible. Scrap may be charged as high density bales, loosely packed bales, or as dry shredded scrap that is continuously fed from a conveyor and into the vortex section of the charging well. The continuous feed system is advantageous when processing uniform scrap directly from a drier (such as a delacquering operation for UBCs).

Demagging reduces the magnesium content of the molten charge from approximately 0.5 percent to about 0.1 percent (a typical product specification). In the past, when demagging with liquid chlorine, chlorine was injected under pressure to react with magnesium as the chlorine bubbled to the surface. The pressurized chlorine was released through carbon lances directed under the heel surface, resulting in high chlorine emissions.

A more recent chlorine aluminum demagging process has replaced the carbon lance procedure. Molten aluminum in the furnace charging well gives up thermal energy to the scrap as scrap is melted. In order to maintain high melt rates in the charging well, a circulation pump moves high temperature molten aluminum from the melt section of the reverberatory furnace to the charging well. Chlorine gas is metered into the circulation pump's discharge pipe. By inserting chlorine gas into the turbulent flow of the molten aluminum at an angle to the aluminum pump discharge, small chlorine-filled gas bubbles are sheared off and mixed rapidly in the turbulent flow found in the pump's discharge pipe. In actual practice, the flow rate of chlorine gas is increased until a slight vapor (aluminum chloride) can be seen above the surface of the molten aluminum. Then the flow rate is decreased until no more vapor is seen. It is reported that chlorine usage approaches the stoichiometric relationship using this process. Chlorine emissions resulting from this procedure have not been made available, but it is anticipated that reductions of chlorine emissions (in the form of chloride compounds) will be reported in the future.

Other chlorinating agents or fluxes, such as anhydrous aluminum chloride or chlorinated organics, are used in demagging operations. Demagging with fluorine is similar to demagging with chlorine, except that aluminum fluoride (AlF₃) is employed instead of chlorine. The AlF₃ reacts with
magnesium to produce molten metallic aluminum and solid magnesium fluoride salt that floats to the surface of the molten aluminum and is trapped in the flux layer.

Degassing is a process used to remove gases entrained in molten aluminum. High-pressure inert gases are released below the molten surface to violently agitate the melt. This agitation causes the entrained gasses to rise to the surface to be absorbed in the floating flux. In some operations, degassing is combined with the demagging operation. A combination demagging and degassing process has been developed that uses a 10 percent concentration of chlorine gas mixed with a nonreactive gas (either nitrogen or argon). The combined high-pressure gases are forced through a hand held nozzle that has a designed distribution pattern of hole sizes across the face of the nozzle. The resulting high turbulent flow and the diluted chlorine content primarily degasses the melt. Chlorine emissions resulting from this process are not available.

Alloying combines aluminum with an alloying agent in order to change its strength and ductility. Alloying agents include zinc, copper, manganese, magnesium, and silicon. The alloying steps include an analysis of the furnace charge, addition of the required alloying agents, and then a reanalysis of the charge. This iterative process continues until the correct alloy is reached.

The skimming operation physically removes contaminated semisolid fluxes (dross, slag, or skimmings) by ladling them from the surface of the melt. Skimming is normally conducted several times during the melt cycle, particularly if the pretreated scrap contains high levels of contamination. Following the last skimming, the melt is allowed to cool before pouring into molds or casting machines.

The crucible smelting/refining process is used to melt small batches of aluminum scrap, generally limited to 500 kg (1,100 lb) or less. The metal-treating process steps are essentially the same as those of reverberatory furnaces.

The induction smelting and refining process is designed to produce aluminum alloys with increased strength and hardness by blending aluminum and hardening agents in an electric induction furnace. The process steps include charging scrap, melting, adding and blending the hardening agent, skimming, pouring, and casting into notched bars. Hardening agents include manganese and silicon.

12.8.3 Emissions And Controls²⁻⁸

The major sources of emissions from scrap pretreatment processes are scrap crushing and screening operations, scrap driers, sweat furnaces, and UBC delacquering systems. Although each step in scrap treatment and smelting/refining is a potential source of emissions, emission factors for scrap treatment processes have not been sufficiently characterized and documented and are therefore not presented below.

Smelting and refining emission sources originate from charging, fluxing, and demagging processes. Tables 12.8-1 and 12.8-2 present emission factors for sweating furnaces, crucible furnaces, reverberatory furnaces, and chlorine demagging process.

Table 12.8-1 (Metric Units)	. PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS ^a
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Operation	Uncontrolled	EMISSION FACTOR RATING	Baghouse	EMISSION FACTOR RATING	Electrostatic Precipitator	EMISSION FACTOR RATING
Sweating furnace ^b (SCC 3-04-001-01)	7.25	E	1.65	Е	ND	NA
Smelting						
Crucible furnace ^b (SCC 3-04-001-02)	0.95	Е	ND	NA	ND	NA
Reverberatory ^c (SCC 3-04-001-03)	2.15	Е	0.65 ^e	Е	0.65	Е
Chlorine demagging ^d (SCC 3-04-001-04)	500	Е	25	Е	ND	Е

^a Reference 3. Emission factors for sweating and smelting furnaces expressed as kg/Mg of metal processed. For chlorine demagging, emission factor is kg/Mg of chlorine used. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Based upon averages of 2 source tests.

^c Uncontrolled, based on averages of 10 source tests. Standard deviation of uncontrolled emission factor is 1.75 kg/Mg (3.5 lb/ton), that of controlled emission factor is 0.15 kg/Mg.

^d Based on average of 10 source tests. Standard deviation of uncontrolled emission factor is 215 kg/Mg; that of controlled emission factor is 18 kg/Mg.

^e This factor may be lower if a coated baghouse is used.

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Table 12.8-2 (English Units). PARTICULATE EMISSION FACTORS FOR SECONDARY ALUMINUM OPERATIONS^a

Operation	Uncontrolled	EMISSION FACTOR RATING	Baghouse	EMISSION FACTOR RATING	Electrostatic Precipitator	EMISSION FACTOR RATING
Sweating furnace ^b (SCC 3-04-001-01)	14.5	Е	3.3	Е	ND	NA
Smelting						
Crucible furnace ^b (SCC 3-04-001-02)	1.9	Е	ND	NA	ND	NA
Reverberatory ^c (SCC 3-04-001-03)	4.3	Е	1.3 ^e	Е	1.3	Е
Chlorine demagging ^d (SCC 3-04-001-04)	1000	Е	50	Е	ND	NA

^a Reference 3. Emission factors for sweating and smelting furnaces expressed as lb/ton of metal processed. For chlorine demagging, emission factor is lb/ton of chlorine used. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Based upon averages of 2 source tests.

^c Uncontrolled, based on averages of 10 source tests. Standard deviation of uncontrolled emission factor is 3.5 lb/ton, that of controlled emission factor is 0.3 lb/ton.

^d Based on average of 10 source tests. Standard deviation of uncontrolled emission factor is 430 lb/ton; that of controlled emission factor is 36 lb/ton.

^e This factor may be lower if a coated baghouse is used.

12.8.3.1 Scrap Pretreatment Emissions -

Mechanical cleaning techniques involve crushing, shredding, and screening and produce metallic and nonmetallic particulates. Burning and drying operations (pyrometallurgic techniques) emit particulates and organic vapors. Afterburners are frequently used to convert unburned VOCs to carbon dioxide and water vapor. Other gases that may be present, depending on the composition of the contaminants, include chlorides, fluorides, and sulfur oxides. Specific emission factors for these gases are not presented due to lack of data. Oxidized aluminum fines blown out of the dryer by the combustion gases contain particulate emissions. Wet scrubbers or fabric filters are sometimes used in conjunction with afterburners.

Mechanically generated dust from rotating barrel dross furnaces constitutes the main air emission of hot dross processing. Some fumes are produced from the fluxing reactions. Fugitive emissions are controlled by enclosing the barrel furnace in a hood system and by ducting the emissions to a fabric filter. Furnace offgas emissions, mainly fluxing salt fume, are often controlled by a venturi scrubber.

Emissions from sweating furnaces vary with the feed scrap composition. Smoke may result from incomplete combustion of organic contaminants (e. g., rubber, oil and grease, plastics, paint, cardboard, paper) that may be present. Fumes can result from the oxidation of magnesium and zinc contaminants and from fluxes in recovered dross and skims.

In dry milling, large amounts of dust are generated from the crushing, milling, screening, air classification, and materials transfer steps. Leaching operations (hydrometallurgic techniques) may produce particulate emissions during drying. Particulate emissions from roasting result from the charring of carbonaceous materials (ash).

12.8.3.2 Smelting/Refining Emissions -

Emissions from reverberatory furnaces represent a significant fraction of the total particulate and gaseous effluent generated in the secondary aluminum industry. Emissions from the charging well consist of organic and inorganic particulate, unburned organic vapors, and carbon dioxide. Emissions from furnace burners contain carbon monoxide, carbon dioxide, sulfuric oxide, and nitrogen oxide. Furnace burner emissions are usually separated from process emissions.

Emissions that result from fluxing operations are dependent upon both the type of fluxing agents and the amount required, which are a function of scrap quality. Emissions may include common fluxing salts such as sodium chloride, potassium chloride, and cryolite. Aluminum and magnesium chloride also may be generated from the fluxing materials being added to the melt. Studies have suggested that fluxing particulate emission are typically less than 1 micrometer in diameter. Specific emission factors for these compounds are not presented due to lack of information.

In the past, demagging represented the most severe source of emissions for the secondary aluminum industry. A more recent process change where chlorine gas is mixed into molten aluminum from the furnace circulation pump discharge may reduce chlorine emissions. However, total chlorine emissions are directly related to the amount of demagging effort and product specifications (the magnesium content in the scrap and the required magnesium reduction). Also, as the magnesium percentage decreases during demagging, a disproportional increase in emissions results due to the decreased efficiency of the scavenging process.

Both the chlorine and aluminum fluoride demagging processes create highly corrosive emissions. Chlorine demagging results in the formation of magnesium chloride that contributes to fumes leaving the dross. Excess chloride combines with aluminum to form aluminum chloride, a

vapor at furnace temperatures, but one that condenses into submicrometer fumes as it cools. Aluminum chloride has an extremely high affinity for water (hygroscopic) and combines with water vapor to form hydrochloric acid. Aluminum chloride and hydrochloric acid are irritants and corrosive. Free chlorine that does not form compounds may also escape from the furnace and become an emission.

Aluminum fluoride (AlF_3) demagging results in the formation of magnesium fluoride as a byproduct. Excess fluorine combines with hydrogen to form hydrogen fluoride. The principal emissions resulting from aluminum fluoride demagging is a highly corrosive fume containing aluminum fluoride, magnesium fluoride, and hydrogen fluoride. The use of $A1F_3$ rather than chlorine in the demagging step reduces demagging emissions. Fluorides are emitted as gaseous fluorides (hydrogen fluoride, aluminum and magnesium fluoride vapors, and silicon tetrafluoride) or as dusts. Venturi scrubbers are usually used for gaseous fluoride emission control.

Tables 12.8-3 and 12.8-4 present particle size distributions and corresponding emission factors for uncontrolled chlorine demagging and metal refining in secondary aluminum reverberatory furnaces.

According to the VOC/PM Speciate Data Base Management System (SPECIATE) data base, the following hazardous air pollutants (HAPs) have been found in emissions from reverberatory furnaces: chlorine, and compounds of manganese, nickel, lead, and chromium. In addition to the HAPs listed for reverberatory furnaces, general secondary aluminum plant emissions have been found to include HAPs such as antimony, cobalt, selenium, cadmium, and arsenic, but specific emission factors for these HAPs are not presented due to lack of information.

In summary, typical furnace effluent gases contain combustion products, chlorine, hydrogen chloride and metal chlorides of zinc, magnesium and aluminum, aluminum oxide and various metals and metal compounds, depending on the quality of scrap charged.

	Particle Distribu	Size ation ^b	Size-Specific Emission Factor ^c (kg/Mg)				
Aerodynamic Particle Diameter (μm)	Chlorine Demagging Refining		Chlorine Demagging	EMISSION FACTOR RATING	Refining	EMISSION FACTOR RATING	
2.5	19.8	50.0	99.5	E	1.08	Е	
6.0	36.9	53.4	184.5	E	1.15	Е	
10.0	53.2	60.0	266.0	Е	1.30	Е	

Table 12.8-3 (Metric Units).PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFICEMISSION FACTORS FOR UNCONTROLLED REVERBERATORY FURNACES IN
SECONDARY ALUMINUM OPERATIONS^a

^a References 4-5.

^b Cumulative weight percent is less than the aerodynamic particle diameter, μm .

^c Size-specific emission factor equals total particulate emission factor multiplied by particle size distribution (percent)/100. From Table 12.8-1, total particulate emission factor for chloride demagging is 500 kg/Mg chlorine used, and for refining, 2.15 kg/Mg aluminum processed.

Table 12.8-4 (English Units).PARTICLE SIZE DISTRIBUTION AND SIZE-SPECIFICEMISSION FACTORS FOR UNCONTROLLED REVERBERATORY FURNACES IN
SECONDARY ALUMINUM OPERATIONS^a

	Particle Distribu	size ition ^b	Size-S	pecific Emissi	on Factor ^e ((lb/ton)
Aerodynamic Particle Diameter (μm)	Chlorine Demagging	Chlorine Demagging Refining		EMISSION FACTOR RATING	Refining	EMISSION FACTOR RATING
2.5	19.8	50.0	199	E	2.16	E
6.0	36.9	53.4	369	Е	2.3	Е
10.0	53.2	60.0	532	E	2.6	Е

^a References 4-5.

^b Cumulative weight percent is less than the aerodynamic particle diameter, μm .

^c Size-specific emission factor equals total particulate emission factor multiplied by particle size distribution (percent)/100. From Table 12.8-2, total particulate emission factor for chloride demagging is 1000 lb/ton chlorine used, and for refining, 4.3 lb/ton aluminum processed.

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12.9 Secondary Copper Smelting

12.9.1 General^{1,2}

As of 1992, more than 40 percent of the U. S. supply of copper is derived from secondary sources, including such items as machine shop punchings, turnings, and borings; manufacturing facility defective or surplus goods; automobile radiators, pipes, wires, bushings, and bearings; and metallurgical process skimmings and dross. This secondary copper can be refined into relatively pure metallic copper, alloyed with zinc or tin to form brass or bronze, incorporated into chemical products, or used in a number of smaller applications. Six secondary copper smelters are in operation in the U. S.: 3 in Illinois and 1 each in Georgia, Pennsylvania, and South Carolina. A large number of mills and foundries reclaim relatively pure copper scrap for alloying purposes.

12.9.2 Process Description^{2,3}

Secondary copper recovery is divided into 4 separate operations: scrap pretreatment, smelting, alloying, and casting. Pretreatment includes the cleaning and consolidation of scrap in preparation for smelting. Smelting consists of heating and treating the scrap for separation and purification of specific metals. Alloying involves the addition of 1 or more other metals to copper to obtain desirable qualities characteristic of the combination of metals. The major secondary copper smelting operations are shown in Figure 12.9-1; brass and bronze alloying operations are shown in Figure 12.9-2.

12.9.2.1 Pretreatment -

Scrap pretreatment may be achieved through manual, mechanical, pyrometallurgical, or hydrometallurgical methods. Manual and mechanical methods include sorting, stripping, shredding, and magnetic separation. The scrap may then be compressed into bricquettes in a hydraulic press. Pyrometallurgical pretreatment may include sweating (the separation of different metals by slowly staging furnace air temperatures to liquify each metal separately), burning insulation from copper wire, and drying in rotary kilns to volatilize oil and other organic compounds. Hydrometallurgical pretreatment methods include flotation and leaching to recover copper from slag. Flotation is typically used when slag contains greater than 10 percent copper. The slag is slowly cooled such that large, relatively pure crystals are formed and recovered. The remaining slag is cooled, ground, and combined with water and chemicals that facilitate flotation. Compressed air and the flotation chemicals separate the ground slag into various fractions of minerals. Additives cause the copper to float in a foam of air bubbles for subsequent removal, dewatering, and concentration.

Leaching is used to recover copper from slime, a byproduct of electrolytic refining. In this process, sulfuric acid is circulated through the slime in a pressure filter. Copper dissolves in the acid to form a solution of copper sulfate ($CuSO_4$), which can then be either mixed with the electrolyte in the refinery cells or sold as a product.

12.9.2.2 Smelting -

Smelting of low-grade copper scrap begins with melting in either a blast or a rotary furnace, resulting in slag and impure copper. If a blast furnace is used, this copper is charged to a converter, where the purity is increased to about 80 to 90 percent, and then to a reverberatory furnace, where copper of about 99 percent purity is achieved. In these fire-refining furnaces, flux is added to the copper and air is blown upward through the mixture to oxidize impurities. These impurities are then



ENTERING THE SYSTEM

Figure 12.9-1. Low-grade copper recovery. (Source Classification Codes in parentheses.)

ENTERING THE SYSTEM

LEAVING THE SYSTEM



Figure 12.9-2. High-grade brass and bronze alloying. (Source Classification Codes in parentheses.)

removed as slag. Then, by reducing the furnace atmosphere, cuprous oxide (CuO) is converted to copper. Fire-refined copper is cast into anodes, which are used during electrolysis. The anodes are submerged in a sulfuric acid solution containing copper sulfate. As copper is dissolved from the anodes, it deposits on the cathode. Then the cathode copper, which is as much as 99.99 percent pure, is extracted and recast. The blast furnace and converter may be omitted from the process if average copper content of the scrap being used is greater than about 90 percent.

The process used by 1 U. S. facility involves the use of a patented top-blown rotary converter in lieu of the blast, converting, and reverberatory furnaces and the electrolytic refining process described above. This facility begins with low-grade copper scrap and conducts its entire refining operation in a single vessel.

12.9.2.3 Alloying -

In alloying, copper-containing scrap is charged to a melting furnace along with 1 or more other metals such as tin, zinc, silver, lead, aluminum, or nickel. Fluxes are added to remove impurities and to protect the melt against oxidation by air. Air or pure oxygen may be blown through

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the melt to adjust the composition by oxidizing excess zinc. The alloying process is, to some extent, mutually exclusive of the smelting and refining processes described above that lead to relatively pure copper.

12.9.2.4 Casting -

The final recovery process step is the casting of alloyed or refined metal products. The molten metal is poured into molds from ladles or small pots serving as surge hoppers and flow regulators. The resulting products include shot, wirebar, anodes, cathodes, ingots, or other cast shapes.

12.9.3 Emissions And Controls³

The principal pollutant emitted from secondary copper smelting activities is particulate matter. As is characteristic of secondary metallurgical industries, pyrometallurgical processes used to separate or refine the desired metal, such as the burning of insulation from copper wire, result in emissions of metal oxides and unburned insulation. Similarly, drying of chips and borings to remove excess oils and cutting fluids can cause discharges of volatile organic compounds (VOC) and products of incomplete combustion.

The smelting process utilizes large volumes of air to oxidize sulfides, zinc, and other undesirable constituents of the scrap. This oxidation procedure generates particulate matter in the exhaust gas stream. A broad spectrum of particle sizes and grain loadings exists in the escaping gases due to variations in furnace design and in the quality of furnace charges. Another major factor contributing to differences in emission rates is the amount of zinc present in scrap feed materials. The low-boiling zinc volatilizes and is oxidized to produce copious amounts of zinc oxide as submicron particulate.

Fabric filter baghouses are the most effective control technology applied to secondary copper smelters. The control efficiency of these baghouses may exceed 99 percent, but cooling systems may be needed to prevent hot exhaust gases from damaging or destroying the bag filters. Electrostatic precipitators are not as well suited to this application, because they have a low collection efficiency for dense particulate such as oxides of lead and zinc. Wet scrubber installations are ineffective as pollution control devices in the secondary copper industry because scrubbers are useful for particles larger than 1 micrometer (μ m), and the metal oxide fumes generated are generally submicron in size.

Particulate emissions associated with drying kilns can also be controlled with baghouses. Drying temperatures up to 150°C (300°F) produce exhaust gases that require no precooling prior to the baghouse inlet. Wire burning generates large amounts of particulate matter, primarily composed of partially combusted organic compounds. These emissions can be effectively controlled by directflame incinerators called afterburners. An efficiency of 90 percent or more can be achieved if the afterburner combustion temperature is maintained above 1000°C (1800°F). If the insulation contains chlorinated organics such as polyvinyl chloride, hydrogen chloride gas will be generated. Hydrogen chloride is not controlled by the afterburner and is emitted to the atmosphere.

Fugitive emissions occur from each process associated with secondary copper smelter operations. These emissions occur during the pretreating of scrap, the charging of scrap into furnaces containing molten metals, the transfer of molten copper from one operation to another, and from material handling. When charging scrap into furnaces, fugitive emissions often occur when the scrap is not sufficiently compact to allow a full charge to fit into the furnace prior to heating. The introduction of additional material onto the liquid metal surface produces significant amounts of volatile and combustible materials and smoke. If this smoke exceeds the capacity of the exiting

capture devices and control equipment, it can escape through the charging door. Forming scrap bricquettes offers a possible means of avoiding the necessity of fractional charges. When fractional charging cannot be eliminated, fugitive emissions are reduced by turning off the furnace burners during charging. This reduces the flow rate of exhaust gases and allows the exhaust control system to better accommodate the additional temporary emissions.

Fugitive emissions of metal oxide fumes are generated not only during melting, but also while pouring molten metal into molds. Additional dusts may be generated by the charcoal or other lining used in the mold. The method used to make "smooth-top" ingots involves covering the metal surface with ground charcoal. This process creates a shower of sparks, releasing emissions into the plant environment at the vicinity of the furnace top and the molds being filled.

The electrolytic refining process produces emissions of sulfuric acid mist, but no data quantifying these emissions are available.

Emission factor averages and ranges for 6 different types of furnaces are presented in Tables 12.9-1 and 12.9-2, along with PM-10 emission rates and reported fugitive and lead emissions. Several of the metals contained in much of the scrap used in secondary copper smelting operations, particularly lead, nickel, and cadmium, are hazardous air pollutants (HAPs) as defined in Title III of the 1990 Clean Air Act Amendments. These metals will exist in the particulate matter emitted from these processes in proportions related to their existence in the scrap.

	Control	Total	EMISSION FACTOR	b	EMISSION FACTOR		EMISSION FACTOR
Furnace And Charge Type	Equipment	Particulate	RATING	PM-10 ⁵	RATING	Lead	RATING
Cupola Scrap iron (SCC 3-04-002-13)	None	0.002	В	ND	NA	ND	NA
Insulated copper wire	None	120	В	105.6	E	ND	NA
(SCC 3-04-002-11)	ESP-) 25	В	ND 22.1	NA	ND ND	NA
(SCC 3-04-002-12)	ESP ^d	33 1.2	B	32.1 ND	E NA	ND ND	NA NA
Fugitive emissions ^b							
(SCC 3-04-002-34)	None	ND	NA	1.1	E	ND	NA
Reverberatory furnace High lead alloy (58%) (SCC 3-04-002-43)	None	ND	NA	ND	NA	25	В
Red/yellow brass (SCC 3-04-002-44)	None	ND	NA	ND	NA	6.6	В
Other alloy (7%) (SCC 3-04-002-42)	None		NA	ND	NA	2.5	В
Copper	None	2.6	В	2.5	Е	ND	NA
(SCC 3-04-002-14)	Baghouse	0.2	B	ND	NA	ND	NA
Brass and bronze	None	18	В	10.8	Е	ND	NA
(SCC 3-04-002-15)	Baghouse	1.3	В	ND	NA	ND	NA
Fugitive emissions ^b	None	ND	NA	1.5	E	ND	NA
(SCC 3-04-002-35)							
Rotary furnace							
Brass and bronze	None	150	В	88.3	E	ND	NA
(SCC 3-04-002-17)	ESP ^a	7	В	ND	NA	ND	NA
Fugitive emissions ^b	None	ND	NA	1.3	E	ND	NA
(SCC 3-04-002-36)							
Crucible and pot furnace						_	
Brass and bronze	None	11	В	6.2	E	ND	NA
(SCC 3-04-002-19)	ESP	0.5	В	ND	NA	ND	NA
Fugitive emissions	None	ND	NA	0.14	E	ND	NA
(SCC 3-04-002-37)						:	
Electric arc furnace							
Copper	None	2.5	В	2.5	E		NA
(SCC 3-04-002-20)	Baghouse	0.5	В	ND	NA	ND	NA
Brass and bronze	None	5.5	В	3.2 ND	E		NA
(SCC 3-04-002-21)	Baghouse	3	В	ND	NA	ND	NA
Electric induction			~	25	F	ND	NT A
Copper	None	3.5	В	3.5	E	ND	NA
(SCC 3-04-002-23)	Baghouse	0.25	В		NA		NA
Brass and bronze	None	10	В		E		
(SCC 3-04-002-24)	Bagnouse	U.30	B NA		NA E		INA NA
rugitive emissions	None	ND	NA	0.04	E		INA
(SCC 3-04-002-38)				[

Table 12.9-1 (Metric Units).PARTICULATE EMISSION FACTORS FOR FURNACES USED
IN SECONDARY COPPER SMELTING AND ALLOYING PROCESS^a

Table 12.9-1 (cont.).

- ^a Expressed as kg of pollutant/Mg ore processed. The information for particulate in Table 12.9-1 was based on unpublished data furnished by the following:
 - Philadelphia Air Management Services, Philadelphia, PA.
 - New Jersey Department of Environmental Protection, Trenton, NJ.
 - New Jersey Department of Environmental Protection, Metro Field Office, Springfield, NJ.
 - New Jersey Department of Environmental Protection, Newark Field Office, Newark, NJ.
 - New York State Department of Environmental Conservation, New York, NY.
 - The City of New York Department of Air Resources, New York, NY.
 - Cook County Department of Environmental Control, Maywood, IL.
 - Wayne County Department of Health, Air Pollution Division, Detroit, MI.
 - City of Cleveland Department of Public Health and Welfare, Division of Air Pollution Control, Cleveland, OH.
 - State of Ohio Environmental Protection Agency, Columbus, OH.
 - City of Chicago Department of Environmental Control, Chicago, IL.
- South Coast Air Quality Management District, Los Angeles, CA.
- ^b PM-10 and fugitive emissions are listed in Airs Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants, U.S Environmental Protection Agency, EPA 450/4-90-003, March 1990. These estimates should be considered to have an EMISSION FACTOR RATING of E.
- ^c References 1,6-7. Expressed as kg of pollutant/Mg product.
- ^d ESP = electrostatic precipitator.

Table 12.9-2 (English Units).PARTICULATE EMISSION FACTORS FOR FURNACESUSED IN SECONDARY COPPER SMELTING AND ALLOYING PROCESS^a

Furnace And Charge Type	Control Equipment	Total Particulate	EMISSION FACTOR RATING	PM-10 ^b	EMISSION FACTOR RATING	Lead ^c	EMISSION FACTOR RATING
Cupala							
Scran iron							
(SCC 3-04-002-13)	None	0.003	в	ND	NA	ND	NΔ
Insulated corport wire	None	230	B	211.6	F		NA NA
(SCC 3-04-002-11)	ESPd	10	B	ND	NA	ND	NA
Scran copper and brass	None	70	B	64.4	E	ND	NA
(SCC 3-04-002-12)	ESP ^d	2.4	_	ND	NA	ND	NA
Fugitive emissions ^b (SCC 3-04-002-34)	None	ND	NA	2.2	E	ND	NA
Reverberatory furnace							
High lead alloy (58%)	None	ND	NA	ND	NA	50	В
(SCC 3-04-002-43)							
Red/yellow brass (SCC 3-04-002-44)	None	ND	NA	ND	NA	13.2	В
Other alloy (7%) (SCC 3-04-002-42)	None	ND	NA	ND	NA	5.0	В
Copper	None	5.1	В	5.1	Е	ND	NA
(SCC 3-04-002-14)	Baghouse	0.4	B	ND	NA	ND	NA
Brass and bronze	None	36	В	21.2	Е	ND	NA
(SCC 3-04-002-15)	Baghouse	2.6	В	ND	NA	ND	NA
Fugitive emissions ^b	None	ND	NA	3.1	Е	ND	NA
(SCC 3-04-002-35)							
Rotary furnace							
Brass and bronze	None	300	В	177.0	Е	ND	NA
(SCC 3-04-002-17)	ESP ^d	13	В	ND	NA	ND	NA
Fugitive emissions ^b	None	ND	NA	2.6	E	ND	NA
(SCC 3-04-002-36)							
Crucible and pot furnace							
Brass and bronze	None	21	В	12.4	E	ND	NA
(SCC 3-04-002-19)	ESP ⁴		В	ND	NA	ND	NA
Fugitive emissions	None	ND	NA	0.29	E	ND	NA
(SCC 3-04-002-37)							
Electric arc furnace							
Copper	None	5	B	5	E	ND	NA
(SCC 3-04-002-20)	Baghouse	1	B	ND		ND	NA
Brass and bronze	None	11	В	6.5	E	ND	NA
(SCC 3-04-002-21)	Baghouse	6	в	ND	NA	ND	NA
Electric induction furnace							
Copper	None	7	В	7	E	ND	NA
(SCC 3-04-002-23)	Baghouse	0.5	В	ND	NA	ND	NA
Brass and bronze	None	20	В	20	E	ND	NA
(SCC 3-04-002-24)	Baghouse	0.7	B	ND	NA	ND	NA
Fugitive emissions	None	ND	NA	0.04	E	ND	NA
(SCC 3-04-002-38)		L			<u> </u>		

Table 12.9-2 (cont.).

- ^a Expressed as lb of pollutant/ton ore processed. The information for particulate in Table 12.9-2 was based on unpublished data furnished by the following:
 Philadelphia Air Management Services, Philadelphia, PA.
 New Jersey Department of Environmental Protection, Trenton, NJ.
 New Jersey Department of Environmental Protection, Metro Field Office, Springfield, NJ.
 New Jersey Department of Environmental Protection, Newark Field Office, Newark, NJ.
 New York State Department of Environmental Conservation, New York, NY.
 The City of New York Department of Air Resources, New York, NY.
 Cook County Department of Environmental Control, Maywood, IL.
 Wayne County Department of Public Health and Welfare, Division of Air Pollution Control, Cleveland, OH.
 State of Ohio Environmental Protection Agency, Columbus, OH.
 City of Chicago Department of Environmental Control, Chicago, IL.
 South Coast Air Quality Management District, Los Angeles, CA.
- ^b PM-10 and fugitive emissions are listed in Airs Facility Subsystem Source Classification Codes and Emission Factor Listing for Criteria Air Pollutants, U.S Environmental Protection Agency, EPA 450/4-90-003, March 1990. These estimates should be considered to have an EMISSION FACTOR RATING of E.
- ^c References 1,6-7. Expressed as lb of pollutant/ton product.
- ^d ESP = electrostatic precipitator.

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- 1. Mineral Commodity Summaries 1992, U. S. Department Of The Interior, Bureau Of Mines.
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- 4. Emission Factors And Emission Source Information For Primary And Secondary Copper Smelters, U. S. Environmental Protection Agency, Research Triangle Park, NC, Publication No. EPA-450/3-051, December 1977.
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12.10 Gray Iron Foundries

12.10.1 General

Iron foundries produce high-strength castings used in industrial machinery and heavy transportation equipment manufacturing. Castings include crusher jaws, railroad car wheels, and automotive and truck assemblies.

Iron foundries cast 3 major types of iron: gray iron, ductile iron, and malleable iron. Cast iron is an iron-carbon-silicon alloy, containing from 2 to 4 percent carbon and 0.25 to 3.00 percent silicon, along with varying percentages of manganese, sulfur, and phosphorus. Alloying elements such as nickel, chromium, molybdenum, copper, vanadium, and titanium are sometimes added. Table 12.10-1 lists different chemical compositions of irons produced.

Mechanical properties of iron castings are determined by the type, amount, and distribution of various carbon formations. In addition, the casting design, chemical composition, type of melting scrap, melting process, rate of cooling of the casting, and heat treatment determine the final properties of iron castings. Demand for iron casting in 1989 was estimated at 9540 million megagrams (10,520 million tons), while domestic production during the same period was 7041 million megagrams (7761 million tons). The difference is a result of imports. Half of the total iron casting were used by the automotive and truck manufacturing companies, while half the total ductile iron castings were pressure pipe and fittings.

Table 12.10-1. CHEMICAL COMPOSITION OF FERROUS CASTINGS BY PERCENTAGES

Element	Gray Iron	Malleable Iron (As White Iron)	Ductile Iron	Steel
Carbon	2.0 - 4.0	1.8 - 3.6	3.0 - 4.0	<2.0 ^a
Silicon	1.0 - 3.0	0.5 - 1.9	1.4 - 2.0	0.2 - 0.8
Manganese	0.40 - 1.0	0.25 - 0.80	0.5 - 0.8	0.5 - 1.0
Sulfur	0.05 - 0.25	0.06 - 0.20	< 0.12	< 0.06
Phosphorus	0.05 - 1.0	0.06 - 0.18	< 0.15	< 0.05

^a Steels are classified by carbon content: low carbon is less than 0.20 percent; medium carbon is 0.20-0.5 percent; and high carbon is greater than 0.50 percent.

12.10.2 Process Description^{1-5,39}

The major production operations in iron foundries are raw material handling and preparation, metal melting, mold and core production, and casting and finishing.

12.10.2.1 Raw Material Handling And Preparation -

Handling operations include the conveying of all raw materials for furnace charging, including metallics, fluxes and fuels. Metallic raw materials are pig iron, iron and steel scrap, foundry returns, and metal turnings. Fluxes include carbonates (limestone, dolomite), fluoride (fluorospar), and

12.10.2.1 Raw Material Handling And Preparation -

Handling operations include the conveying of all raw materials for furnace charging, including metallics, fluxes and fuels. Metallic raw materials are pig iron, iron and steel scrap, foundry returns, and metal turnings. Fluxes include carbonates (limestone, dolomite), fluoride (fluorospar), and carbide compounds (calcium carbide). Fuels include coal, oil, natural gas, and coke. Coal, oil, and natural gas are used to fire reverberatory furnaces. Coke, a derivative of coal, is used for electrodes required for heat production in electric arc furnaces.

As shown in Figure 12.10-1, the raw materials, metallics, and fluxes are added to the melting furnaces directly. For electric induction furnaces, however, the scrap metal added to the furnace charge must first be pretreated to remove grease and oil. Scrap metals may be degreased with solvents, by centrifugation, or by preheating to combust the organics.

12.10.2.2 Metal Melting -

The furnace charge includes metallics, fluxes, and fuels. Composition of the charge depends upon specific metal characteristics required. The basic melting process operations are furnace operations, including charging, melting, and backcharging; refining, during which the chemical composition is adjusted to meet product specifications; and slag removal and molding the molten metal.

12.10.2.2.1 Furnace Operations -

The 3 most common furnaces used in the iron foundry industry are cupolas, electric arc, and electric induction furnaces. The cupola is the major type of furnace used in the iron foundry industry. It is typically a cylindrical steel shell with a refractory-lined or water-cooled inner wall. The cupola is the only furnace type that uses coke as a fuel. Iron is melted by the burning coke and flows down the cupola. As the melt proceeds, new charges are added at the top. The flux combines with nonmetallic impurities in the iron to form slag, which can be removed. Both the molten iron and the slag are removed at the bottom of the cupola.

Electric arc furnaces (EAFs) are large, welded steel cylindrical vessels equipped with a removable roof through which 3 retractable carbon electrodes are inserted. The electrodes are lowered through the roof of the furnace and are energized by 3-phase alternating current, creating arcs that melt the metallic charge with their heat. Electric arc furnace capacities range from 5 to 345 megagrams (6 to 380 tons). Additional heat is produced by the resistance of the metal between the arc paths. Once the melting cycle is complete, the carbon electrodes are raised and the roof is removed. The vessel can then be tilted to pour the molten iron.

Electric induction furnaces are cylindrical or cup-shaped refractory-lined vessels that are surrounded by electrical coils. When these coils are energized with high frequency alternating current, they produce a fluctuating electromagnetic field which heats the metal charge. The induction furnace is simply a melting furnace to which high-grade scrap is added to make the desired product. Induction furnaces are kept closed except when charging, skimming and tapping. The molten metal is tapped by tilting and pouring through a hole in the side of the vessels.

12.10.2.2.2 Refining -

Refining is the process in which magnesium and other elements are added to molten iron to produce ductile iron. Ductile iron is formed as a steel matrix containing spheroidal particles (or nodules) of graphite. Ordinary cast iron contains flakes of graphite. Each flake acts as a crack, which makes cast iron brittle. Ductile irons have high tensile strength and are silvery in appearance.



Figure 12.10-1. Flow diagram of a typical iron foundry. (Source Classification Codes in parentheses.)

Two widely used refining processes are the plunge method and the pour-over method. In plunging, magnesium or a magnesium alloy is loaded into a graphite "bell" which is plunged into a ladle of molten iron. A turbulent reaction takes place as the magnesium boils under the heat of the molten iron. As much as 65 percent of the magnesium may be evaporated. The magnesium vapor ignites in air, creating large amounts of smoke.

In the pour-over method, magnesium alloy is placed in the bottom of a vessel and molten iron is poured over it. Although this method produces more emissions and is less efficient than plunging, it requires no capital equipment other than air pollution control equipment.

12.10.2.2.3 Slag Removal And Molding -

Slag is removed from furnaces through a tapping hole or door. Since slag is lighter than molten iron, it remains on top of the molten iron and can be raked or poured out. After slag has been removed, the iron is cast into molds.

12.10.2.3 Mold And Core Production -

Molds are forms used to shape the exterior of castings. Cores are molded sand shapes used to make internal voids in castings. Molds are prepared from wet sand, clay, and organic additives, and are usually dried with hot air. Cores are made by mixing sand with organic binders or organic polymers, molding the sand into a core, and baking the core in an oven. Used sand from castings shakeout is recycled and cleaned to remove any clay or carbonaceous buildup. The sand is screened and reused to make new molds.

12.10.2.4 Casting And Finishing -

Molten iron is tapped into a ladle or directly into molds. In larger, more mechanized foundries, filled molds are conveyed automatically through a cooling tunnel. The molds are then placed on a vibrating grid to shake the mold sand and core sand loose from the casting.

12.10.3 Emissions And Controls^{9,31,52}

Emission points and types of emissions from a typical foundry are shown in Figure 12.10-2. Emission factors are presented in Tables 12.10-2, 12.10-3, 12.10-4, 12.10-5, 12.10-6, 12.10-7, 12.10-8, and 12.10-9.

12.10.3.1 Raw Material Handling And Preparation -

Fugitive particulate emissions are generated from the receiving, unloading, and conveying of raw materials. These emissions can be controlled by enclosing the points of disturbance (e. g., conveyor belt transfer points) and routing air from enclosures through fabric filters or wet collectors.

Scrap preparation with heat will emit smoke, organic compounds, and carbon monoxide; scrap preparation with solvent degreasers will emit organics. Catalytic incinerators and afterburners can control about 95 percent of organic and carbon monoxide emissions (see Section 4.6, "Solvent Degreasing").

12.10.3.2 Metal Melting -

Emissions released from melting furnaces include particulate matter, carbon monoxide, organic compounds, sulfur dioxide, nitrogen oxides, and small quantities of chloride and fluoride compounds. The particulates, chlorides, and fluorides are generated from incomplete combustion of carbon additives, flux additions, and dirt and scale on the scrap charge. Organic material on scrap and furnace temperature affect the amount of carbon monoxide generated. Fine particulate fumes



Figure 12.10-2. Emission points in a typical iron foundry. (Source Classification Codes in parentheses.)

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Process	Control Device	Total Particulate	EMISSION FACTOR RATING
Cupola (SCC $3-04-003-01$)	Uncontrolled ^b	69	F
	Camulhar ^Q	1.6	E
	Scrubber	1.0	C
	Venturi scrubber ^d	1.5	C
	Electrostatic precipitator ^e	0.7	Е
	Baghouse ^f	0.3	Е
	Single wet cap ^g	4.0	Е
	Impingement scrubber ^g	2.5	Е
	High-energy scrubber ^g	0.4	Е
Electric arc furnace	Uncontrolled ^h	6.3	С
(SCC 3-04-003-04)	Baghouse ⁱ	0.2	С
Electric induction	Uncontrolled ^k	0.5	Е
furnace (SCC 3-04-003-03)	Baghouse ^m	0.1	Е
Reverberatory	Uncontrolled ⁿ	1.1	Е
(SCC 3-04-003-02)	Baghouse ^m	0.1	Е

Table 12.10-2 (Metric Units). PARTICULATE EMISSION FACTORS FOR IRON FURNACES^a

^a Emission Factors are expressed in kg of pollutant/Mg of gray iron produced.
^b References 1,7,9,10. SCC = Source Classification Code.
^c References 12,15. Includes averages for wet cap and other scrubber types not already listed.

^d References 12,17,19.

^e References 8,11.

^f References 12-14.

- ^g References 8,11,29,30.
- ^h References 1,6,23.

^j References 6,23,24.
^k References 1,12. For metal melting only.

^m Reference 4.

ⁿ Reference 1.

Process	Control Device	Total Particulate	EMISSION FACTOR RATING
Cupola (SCC 3-04-003-01)	Uncontrolled ^b	13.8	Е
	Scrubber ^c	3.1	С
	Venturi scrubber ^d	3.0	С
	Electrostatic precipitator ^e	1.4	Е
	Baghouse ^f	0.7	Е
	Single wet cap ^g	8.0	Е
	Impingement scrubber ^g	5.0	Е
	High energy scrubber ^g	0.8	E
Electric arc furnace	Uncontrolled ^h	12.7	С
(SCC 3-04-003-04)	Baghouse ^j	0.4	С
Electric induction	Uncontrolled ^k	0.9	E
furnace (SCC 3-04-003-03)	Baghouse ^m	0.2	E
Reverberatory	Uncontrolled ⁿ	2.1	Е
(SCC 3-04-003-02)	Baghouse ^m	0.2	E

Table 12.10-3 (English Units). PARTICULATE EMISSION FACTORS FOR IRON FURNACES^a

^a Emission Factors expressed as lb of pollutant/ton of gray iron produced.

^b References 1,7,9,10. SCC = Source Classification Code.

^c References 12,15. Includes averages for wet cap and other scrubber types not already listed.

^d References 12, 17, 19.

^e References 8,11.

- ^f References 12-14.
- ^g References 8,11,29,30.
- ^h References 1,6,23.
- ^j References 6,23,24.
- ^k References 1,12. For metal melting only.
- ^m Reference 4.
- ⁿ Reference 1.

Table 12.10-4 (Metric Units). CRITERIA GASEOUS AND LEAD EMISSION FACTORS FOR IRON FOUNDRIES^a

Ентасе Туре	co	EMISSION FACTOR RATING	SO ₂	EMISSION FACTOR RATING	NO.	EMISSION FACTOR RATING	voc	EMISSION FACTOR RATING	Lead ^b	EMISSION FACTOR RATING
					X					
Cupola (SCC 3-04-003-01) Uncontrolled	73°	Е	0.65 ^d	Е	ND	NA	ND	NA	0.05-0.6	В
High energy scrubber	73	Е	0.35 ^d	Е	ND	NA	ND	NA	ND	NA
Electric arc ^e (SCC 3-04-003-04)	0.5-19	E	Neg	E	0.02-0.3	Е	0.03- 0 .15	E	ND	NA
Electric induction ^f (SCC 3-04-003-03)	Neg	E	Neg	E	ND	NA	ND	NA	0.005-0.05	В
Reverberatory (SCC 3-04-003-02)	ND	NA	ND	NA	ND	NA	ND	NA	0.006-0.07	В

^a Expressed as kg of pollutant/Mg of gray iron produced. SCC = Source Classification Code. Neg = negligible. ND = no data. ^b References 11,31,34.
^c Reference 2.
^d Reference 4. S = % sulfur in the coke. Assumes 30% of sulfur is converted to SO₂.
^e Reference 4,6.
^f References 8,11,29-30.

Table 12.10-5 (English Units). CRITERIA GASEOUS AND LEAD EMISSION FACTORS FOR IRON FOUNDRIES^a

Furnace Type	со	EMISSION FACTOR RATING	SO2	EMISSION FACTOR RATING	NO _x	EMISSION FACTOR RATING	VOC	EMISSION FACTOR RATING	Lead ^b	EMISSION FACTOR RATING
Cupola (SCC 3-04-003-01) Uncontrolled	145°	E	1.28 ^d	E	ND	NA	ND	NA	0.1-1.1	В
High energy scrubber	145	Е	0.6S ^đ	Е	ND	NA	ND	NA	ND	NA
Electric arc ^e (SCC 3-04-003-04)	1-37	Е	Neg	E	0.04-0.6	E	0.06-0.3	E	ND	NA
Electric induction ^f (SCC 3-04-003-03)	Neg	E	Neg	Е	ND	NA	ND	NA	0.009-0.1	В
Reverberatory (SCC 3-04-003-02)	ND	NA	ND	NA	ND	NA	ND	NA	0.012-0.14	В

^a Expressed as lb of pollutant/ton of gray iron produced. SCC = Source Classification Code. Neg = negligible. ND = no data. NA = not applicable. ^b References 11,31,34.

^c Reference 2.

^d Reference 4. S = % sulfur in the coke. Assumes 30% of sulfur is converted to SO₂.
^e Reference 4,6.
^f References 8,11,29-30.

Table 12.10-6 (Metric Units). PARTICULATE EMISSION FACTORS FOR ANCILLARY OPERATIONS AND FUGITIVE SOURCES AT GRAY IRON FOUNDRIES^a

Process	Control Device	Total Emission Factor	EMISSION FACTOR RATING	Emitted To Work Environment	EMISSION FACTOR RATING	Emitted To Atmosphere	EMISSION FACTOR RATING
Scrap and charge handling, heating ^b (SCC 3-04-003-15)	Uncontrolled	0.3	Е	0.25	Е	0.1	E
Magnesium treatment ^c (SCC 3-04-003-21)	Uncontrolled	0.9	E	0.9	Е	0.2	Е
Refining ^d (SCC 3-04-003-22)	Uncontrolled	1.5-2.5	Е				
Pouring, cooling ^e (SCC 3-04-003-18)	Uncontrolled	2.1	Е				
Shakeout ^f (SCC 3-04-003-31)	Uncontrolled ^c	1.6	Е				
Cleaning, finishing ^b (SCC 3-04-003-40)	Uncontrolled	8.5	Е	0.15	E	0.05	Е
Sand handling (in kg/Mg sand handled) (SCC 3-04-003-50)	Uncontrolled ^c Scrubber ^g Baghouse ^h	1.8 0.023 0.10	E D E				
Core making, baking ^b (SCC 3-04-003-19)	Uncontrolled	0.6	Е	0.6	Е	0.6	Е

^a Expressed as kg of pollutant/Mg of gray iron produced. SCC = Source Classification Code.
 ^b Reference 4.

^c Reference 1,4. ^d Reference 35.

^e References 1,3,25.

f Reference 1.

^g References 12,27.

^h Reference 12.

Table 12.10-7 (English Units). PARTICULATE EMISSION FACTORS FOR ANCILLARY OPERATIONS AND FUGITIVE SOURCES AT GRAY IRON FOUNDRIES^a

Process	Control Device	Total Emission Factor	EMISSION FACTOR RATING	Emitted To Work Environment	EMISSION FACTOR RATING	Emitted To Atmosphere	EMISSION FACTOR RATING
Scrap and charge handling, heating ^b (SCC 3-04-003-15)	Uncontrolled	0.6	E	0.5	Е	0.2	Е
Magnesium treatment ^c (SCC 3-04-003-21)	Uncontrolled	1.8	Е	1.8	Е	0.4	Е
Refining ^d (SCC 3-04-003-22)	Uncontrolled	. 3 - 5	Е				
Pouring, cooling ^c (SCC 3-04-003-18)	Uncontrolled	4.2	E				
Shakeout ^f (SCC 3-04-003-31)	Uncontrolled ^c	3.2	E				
Cleaning, finishing ^b (SCC 3-04-003-40)	Uncontrolled	17	Е	0.3	Е	0.1	Е
Sand handling (in kg/Mg sand handled) (SCC 3-04-003-50)	Uncontrolled ^c Scrubber ^g Baghouse ^h	3.6 0.046 0.20	E D E				
Core making, baking ^b (SCC 3-04-003-19)	Uncontrolled	1.1	Е	1.1	E	1.1	E

^a Expressed as lb of pollutant/ton of gray iron produced. SCC = Source Classification Code.

^b Reference 4.

- ^c Reference 1,4.
- ^d Reference 35.
- ^e References 1,3,25.
- f Reference 1.
- ^g References 12,27.
- ^h Reference 12.

Metallurgical Industry

			Cumulative	
			Mass Emission	EMISSION
-	Particle Size	Cumulative Mass	Factor	FACTOR
Source	(μm)	$\% \leq \text{Stated Size}^{\text{D}}$	(kg/Mg metal)	RATING
Cupola furnace ^b				
(SCC 3-04-003-01)				
Uncontrolled	0.5	44.3	2 1	C
Uncontrolled	1.0	60 1	3.1 4 8	C
	2.0	79.6	55	
	2.5	84.0	5.8	
	5.0	90.1	6.2	
	10.0	90.1	6.2	
	15.0	90.6	6.3	
		100.0	6.9	
Controlled by baghouse	0.5	83.4	0.33	Е
	1.0	91.5	0.37	
	2.0	94.2	0.38	
	2.5	94.9	0.38	
	5.0	94.9	0.38	
	10.0	94.9	0.38	
	15.0	95.0	0.38	
		100.0	0.4	
Controlled by venturi	0.5	56.0	0.84	С
scrubber ^c	1.0	70.2	1.05	
	2.0	77.4	1.16	
	2.5	77.7	1.17	
	5.0	77.7	1.17	
	10.0	77.7	1.17	
	15.0	100.0	1.1/	
		100.0	1.50	
Electric arc furnaced				
(SCC 3-04-003-04)				
Uncontrolled	1.0	13.0	0.8	E
	2.0	57.5	3.7	
	5.0	82.0	5.2	
	10.0	90.0	5.8	
	15.0	93.5	6.0	
		100.0	6.4	

Table 12.10-8 (Metric Units).PARTICLE SIZE DISTRIBUTION DATAAND EMISSION FACTORS FOR GRAY IRON FOUNDRIES^a

Table	12.	10-8	(cont.)
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Source	Particle Size (µm)	Cumulative Mass % ≤ Stated Size ^b	Cumulative Mass Emission Factor (kg/Mg metal)	EMISSION FACTOR RATING
Pouring, cooling ^b (SCC 3-04-0030-18)				
Uncontrolled	0.5 1.0 2.0 2.5 5.0 10.0 15.0	d 19.0 20.0 24.0 34.0 49.0 72.0 100.0	ND 0.40 0.42 0.50 0.71 1.03 1.51 2.1	D
Shakeout ^b (SCC 3-04-003-31)				
Uncontrolled	0.5 1.0 2.0 2.5 5.0 10.0 15.0	23.0 37.0 41.0 42.0 44.0 70.0 99.9 100.0	0.37 0.59 0.66 0.67 0.70 1.12 1.60 1.60	Ε

^a Emission Factor expressed as kg of pollutant/Mg of metal produced. Mass emission rate data available in Tables 12.10-2 and 12.10-6 to calculate size-specific emission factors. SCC = Source Classification Code. ND = no data.

^b References 13,21,22,25,26.

 ^c Pressure drop across venturi: approximately 25 kPa of water.
 ^d Reference 3, Exhibit VI-15. Averaged from data on 2 foundries. Because original test data could not be obtained, EMISSION FACTOR RATING is E.

Source	Particle Size	Cumulative Mass % ≤ Stated Size ^b	Cumulative Mass Emission Factor	EMISSION FACTOR BATING
Cupola furnace ^b	(µm)	5120		KAIIIO
(SCC 3-04-003-01)				
Uncontrolled	0.5	44.3	6.2	С
	1.0	69.1	9.6	
	2.0	79.6	11.0	
	2.5	84.0	11.6	
	5.0	90.1	12.4	
	10.0	90.1	12.4	
	15.0	90.6	12.6	
		100.0	13.8	
Controlled by baghouse	0.5	83.4	0.66	Е
	1.0	91.5	0.74	
	2.0	94.2	0.76	
	2.5	94.9	0.76	
	5.0	94.9	0.76	
	10.0	95.0	0.76	
	15.0	100.0	0.80	
Controlled by venturi scrubber ^c	0.5	56.0	1.68	С
	1.0	70.2	2.10	Ũ
	2.0	77.4	2.32	
	2.5	77.7	2.34	
	5.0	77.7	2.34	
	10.0	77.7	2.34	
	15.0	77.7	2.34	
		100.0	3.0	
Electric arc furnace ^d (SCC 3-04-003-04)				
Uncontrolled	1.0	13.0	1.6	Е
	2.0	57.5	7.4	~
	5.0	82.0	10.4	
	10.0	90.0	11.6	
	15.0	93.5	12.0	
		100.0	12.8	

Table 12.10-9 (English Units). PARTICLE SIZE DISTRIBUTION DATA AND EMISSION FACTORS FOR GRAY IRON FOUNDRIES^a

Source	Particle Size (µm)	Cumulative Mass % ≤ Stated Size ^b	Cumulative Mass Emission Factor (lb/ton metal)	EMISSION FACTOR RATING
Pouring, cooling ^b (SCC 3-04-003-18)				i
Uncontrolled	0.5 1.0 2.0 2.5 5.0 10.0 15.0	d 19.0 20.0 24.0 34.0 49.0 72.0 100.0	ND 0.80 0.84 1.00 1.42 2.06 3.02 4.2	D
Shakeout ^b (SCC 3-04-003-31)				
Uncontrolled	0.5 1.0 2.0 2.5 5.0 10.0 15.0	23.0 37.0 41.0 42.0 44.0 70.0 99.9 100.0	0.74 1.18 1.32 1.34 1.40 2.24 3.20 3.20	Ε

Table 12.10-9 (cont.)

^a Emission factors are expressed as 1b of pollutant/ton of metal produced. Mass emission rate data available in Tables 12.10-3 and 12.10-7 to calculate size-specific emission factors.

SCC = Source Classification Code. ND = no data.

^b References 13,21-22,25-26.

^c Pressure drop across venturi: approximately 102 inches of water.

^d Reference 3, Exhibit VI-15. Averaged from data on 2 foundries. Because original test data could not be obtained, EMISSION FACTOR RATING is E.

backcharging, alloying, slag removal, and tapping operations. These emissions can escape into the furnace building or can be collected and vented through roof openings. Emission controls for melting and refining operations involve venting furnace gases and fumes directly to a control device. Canopy hoods or special hoods near furnace doors and tapping points capture emissions and route them to emission control systems.

12.10.3.2.1 Cupolas -

Coke burned in cupola furnaces produces several emissions. Incomplete combustion of coke causes carbon monoxide emissions and sulfur in the coke gives rise to sulfur dioxide emissions. High energy scrubbers and fabric filters are used to control particulate emissions from cupolas and electric arc furnaces and can achieve efficiencies of 95 and 98 percent, respectively. A cupola furnace typically has an afterburner as well, which achieves up to 95 percent efficiency. The afterburner is located in the furnace stack to oxidize carbon monoxide and burn organic fumes, tars, and oils.

Reducing these contaminants protects the particulate control device from possible plugging and explosion.

Toxic emissions from cupolas include both organic and inorganic materials. Cupolas produce the most toxic emissions compared to other melting equipment.

12.10.3.2.2 Electric Arc Furnaces -

During melting in an electric arc furnace, particulate emissions of metallic and mineral oxides are generated by the vaporization of iron and transformation of mineral additives. This particulate matter is controlled by high-energy scrubbers (45 percent efficiency) and fabric filters (98 percent efficiency). Carbon monoxide emissions result from combustion of graphite from electrodes and carbon added to the charge. Hydrocarbons result from vaporization and incomplete combustion of any oil remaining on the scrap iron charge.

12.10.3.2.3 Electric Induction Furnaces -

Electric induction furnaces using clean steel scrap produce particulate emissions comprised largely of iron oxides. High emissions from clean charge emissions are due to cold charges, such as the first charge of the day. When contaminated charges are used, higher emissions rates result.

Dust emissions from electric induction furnaces also depend on the charge material composition, the melting method (cold charge or continuous), and the melting rate of the materials used. The highest emissions occur during a cold charge.

Because induction furnaces emit negligible amounts of hydrocarbon and carbon monoxide emissions and relatively little particulate, they are typically uncontrolled, except during charging and pouring operations.

12.10.3.2.4 Refining -

Particulate emissions are generated during the refining of molten iron before pouring. The addition of magnesium to molten metal to produce ductile iron causes a violent reaction between the magnesium and molten iron, with emissions of magnesium oxides and metallic fumes. Emissions from pouring consist of metal fumes from the melt, and carbon monoxide, organic compounds, and particulate evolved from the mold and core materials. Toxic emissions of particulate, arsenic, chromium, halogenated hydrocarbons, and aromatic hydrocarbons are released in the refining process. Emissions from pouring normally are captured by a collection system and vented, either controlled or uncontrolled, to the atmosphere. Emissions continue as the molds cool. A significant quantity of particulate is also generated during the casting shakeout operation. These fugitive emissions are controlled by either high energy scrubbers or fabric filters.

12.10.3.3 Mold And Core Production -

The major pollutant emitted in mold and core production operations is particulate from sand reclaiming, sand preparation, sand mixing with binders and additives, and mold and core forming. Organics, carbon monoxide, and particulate are emitted from core baking and organic emissions from mold drying. Fabric filters and high energy scrubbers generally are used to control particulate from mold and core production. Afterburners and catalytic incinerators can be used to control organics and carbon monoxide emissions.

In addition to organic binders, molds and cores may be held together in the desired shape by means of a cross-linked organic polymer network. This network of polymers undergoes thermal decomposition when exposed to the very high temperatures of casting, typically 1400°C (2550°F). At these temperatures it is likely that pyrolysis of the chemical binder will produce a complex of free

radicals which will recombine to form a wide range of chemical compounds having widely differing concentrations.

There are many different types of resins currently in use having diverse and toxic compositions. There are no data currently available for determining the toxic compounds in a particular resin which are emitted to the atmosphere and to what extent these emissions occur.

12.10.3.4 Casting And Finishing -

Emissions during pouring include decomposition products of resins, other organic compounds, and particulate matter. Finishing operations emit particulates during the removal of burrs, risers, and gates, and during shot blast cleaning. These emissions are controlled by cyclone separators and fabric filters. Emissions are related to mold size, mold composition, sand to metal ratio, pouring temperature, and pouring rate.

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12.11 Secondary Lead Processing

12.11.1 General

Secondary lead smelters produce lead and lead alloys from lead-bearing scrap material. More than 60 percent of all secondary lead is derived from scrap automobile batteries. Each battery contains approximately 8.2 kg (18 lb) of lead, consisting of 40 percent lead alloys and 60 percent lead oxide. Other raw materials used in secondary lead smelting include wheel balance weights, pipe, solder, drosses, and lead sheathing. Lead produced by secondary smelting accounts for half of the lead produced in the U. S. There are 42 companies operating 50 plants with individual capacities ranging from 907 megagrams (Mg) (1,000 tons) to 109,000 Mg (120,000 tons) per year.

12.11.2 Process Description¹⁻⁷

Secondary lead smelting includes 3 major operations: scrap pretreatment, smelting, and refining. These are shown schematically in Figure 12.11-1A, Figure 12.11-1B, and Figure 12.11-1C, respectively.

12.11.2.1 Scrap Pretreatment -

Scrap pretreatment is the partial removal of metal and nonmetal contaminants from leadbearing scrap and residue. Processes used for scrap pretreatment include battery breaking, crushing, and sweating. Battery breaking is the draining and crushing of batteries, followed by manual separation of the lead from nonmetallic materials. Lead plates, posts, and intercell connectors are collected and stored in a pile for subsequent charging to the furnace. Oversized pieces of scrap and residues are usually put through jaw crushers. This separated lead scrap is then sweated in a gas- or oil-fired reverberatory or rotary furnace to separate lead from metals with higher melting points. Rotary furnaces are usually used to process low-lead-content scrap and residue, while reverberatory furnaces are used to process high-lead-content scrap. The partially purified lead is periodically tapped from these furnaces for further processing in smelting furnaces or pot furnaces.

12.11.2.2 Smelting -

Smelting produces lead by melting and separating the lead from metal and nonmetallic contaminants and by reducing oxides to elemental lead. Smelting is carried out in blast, reverberatory, and rotary kiln furnaces. Blast furnaces produce hard or antimonial lead containing about 10 percent antimony. Reverberatory and rotary kiln furnaces are used to produce semisoft lead containing 3 to 4 percent antimony; however, rotary kiln furnaces are rarely used in the U. S. and will not be discussed in detail.

In blast furnaces pretreated scrap metal, rerun slag, scrap iron, coke, recycled dross, flue dust, and limestone are used as charge materials to the furnace. The process heat needed to melt the lead is produced by the reaction of the charged coke with blast air that is blown into the furnace. Some of the coke combusts to melt the charge, while the remainder reduces lead oxides to elemental lead. The furnace is charged with combustion air at 3.4 to 5.2 kPa (0.5 to 0.75 psi) with an exhaust temperature ranging from 650 to 730° C (1200 to 1350° F).

As the lead charge melts, limestone and iron float to the top of the molten bath and form a flux that retards oxidation of the product lead. The molten lead flows from the furnace into a holding pot at a nearly continuous rate. The product lead constitutes roughly 70 percent of the charge. From
PRETREATMENT

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Figure 12.11-1A. Process flow for typical secondary lead smelting. (Source Classification Codes in parentheses.)

EMISSION FACTORS

SMELTING



Figure 12.11-1B. Process flow for typical secondary lead smelting. (Source Classification Codes in parentheses.)

REFINING



Figure 12.11-1C. Process flow for typical secondary lead smelting. (Source Classification Codes in parentheses.)

the holding pot, the lead is usually cast into large ingots called pigs or sows. About 18 percent of the charge is recovered as slag, with about 60 percent of this being a sulfurous slag called matte. Roughly 5 percent of the charge is retained for reuse, and the remaining 7 percent of the charge escapes as dust or fume. Processing capacity of the blast furnace ranges from 18 to 73 Mg per day (20 to 80 tons per day).

The reverberatory furnace used to produce semisoft lead is charged with lead scrap, metallic battery parts, oxides, drosses, and other residues. The charge is heated directly to a temperature of 1260°C (2300°F) using natural gas, oil, or coal. The average furnace capacity is about 45 megagrams (50 tons) per day. About 47 percent of the charge is recovered as lead product and is periodically tapped into molds or holding pots. Forty-six percent of the charge is removed as slag and is later processed in blast furnaces. The remaining 7 percent of the furnace charge escapes as dust or fume.

12.11.2.3 Refining -

Refining and casting the crude lead from the smelting furnaces can consist of softening, alloying, and oxidation depending on the degree of purity or alloy type desired. These operations are batch processes requiring from 2 hours to 3 days. These operations can be performed in reverberatory furnaces; however, kettle-type furnaces are most commonly used. Remelting process is usually applied to lead alloy ingots that require no further processing before casting. Kettle furnaces used for alloying, refining, and oxidizing are usually gas- or oil-fired, and have typical capacities of 23 to 136 megagrams (25 to 150 tons) per day. Refining and alloying operating temperatures range from 320 to 700°C (600 to 1300°F). Alloying furnaces simply melt and mix ingots of lead and alloy materials. Antimony, tin, arsenic, copper, and nickel are the most common alloying materials.

Refining furnaces are used to either remove copper and antimony for soft lead production, or to remove arsenic, copper, and nickel for hard lead production. Sulfur may be added to the molten lead bath to remove copper. Copper sulfide skimmed off as dross may subsequently be processed in a blast furnace to recover residual lead. Aluminum chloride flux may be used to remove copper, antimony, and nickel. The antimony content can be reduced to about 0.02 percent by bubbling air through the molten lead. Residual antimony can be removed by adding sodium nitrate and sodium hydroxide to the bath and skimming off the resulting dross. Dry drossing consists of adding sawdust to the agitated mass of molten metal. The sawdust supplies carbon to help separate globules of lead suspended in the dross and to reduce some of the lead oxide to elemental lead.

Oxidizing furnaces, either kettle or reverberatory units, are used to oxidize lead and to entrain the product lead oxides in the combustion air stream for subsequent recovery in high-efficiency baghouses.

12.11.3 Emissions And Controls^{1,4-5}

Emission factors for controlled and uncontrolled processes and fugitive particulate are given in Tables 12.11-1, 12.11-2, 12.11-3, and 12.11-4. Particulate emissions from most processes are based on accumulated test data, whereas fugitive particulate emissions are based on the assumption that 5 percent of uncontrolled stack emissions are released as fugitive emissions.

Reverberatory and blast furnaces account for the vast majority of the total lead emissions from the secondary lead industry. The relative quantities emitted from these 2 smelting processes cannot be specified, because of a lack of complete information. Most of the remaining processes are small emission sources with undefined emission characteristics.

	Particulate ^b				Lead ^b			SO2		
Process	Uncontroll ed	EMISSION FACTOR RATING	Controlled	EMISSION FACTOR RATING	Uncontrolled	EMISSION FACTOR RATING	Controlled	EMISSION FACTOR RATING	Uncontrolled	EMISSION FACTOR RATING
Sweating ^c (kg/Mg charge) (SCC 3-04-004-04)	16-35	E	ND	NA	4-8 ^d	E	ND	NA	ND	ND
Reverberatory smelting (SCC 3-04-004-02)	162 (87-242) ^e	С	0.50 (0.26-0.77) ^f	с	32 (17-48) ^g	С	ND	NA	40 (36-44) ^f	С
Blast smelting-cupola ^h (SCC 3-04-004-03)	153 (92-207) ^j	С	1.12 (0.11-2.49) ^k	с	52 (31-70) ^m	С	0.15 (0.02-0.32) ⁿ	с	27 (9-55) [¢]	С
Kettle refining (SCC 3-04-004-26)	0.02 ^p	С	ND	NA	0.006 ^p	С	ND	NA	ND	NA
Kettle Oxidation (SCC 3-04-004-08)	≤ 20 ^q	Е	ND	NA	ND	NA	ND	NA	ND	NA
Casting (SCC 3-04-004-09)	0.02 ^p	С	ND	NA	0.007 ^p	С	ND	NA	ND	NA

Table 12.11-1 (Metric Units). EMISSION FACTORS FOR SECONDARY LEAD PROCESSING^a

^a Emission factor units expressed as kg of pollutant/Mg metal produced. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Particulate and lead emission factors are based on quantity of lead product produced, except as noted.

^c Reference 1. Estimated from sweating furnace emissions from nonlead secondary nonferrous processing industries.

^d References 3,5. Based on assumption that uncontrolled reverberatory furnace flue emissions are 23% lead.

e References 8-11.

^f References 6,8-11.

^g Reference 13. Uncontrolled reverberatory furnace flue emissions assumed to be 23% lead. Blast furnace emissions have lead content of 34%, based on single uncontrolled plant test.

^h Blast furnace emissions are combined flue gases and associated ventilation hood streams (charging and tapping).

^j References 8,11-12.

^k References 6,8,11-12,14-15.

^m Reference 13. Blast furnace emissions have lead content of 26%, based on single controlled plant test.

ⁿ Based on quantity of material charged to furnaces.

^p Reference 13. Lead content of kettle refining emissions is 40% and of casting emissions is 36%.

⁴ References 1-2. Essentially all product lead oxide is entrained in an air stream and subsequently recovered by baghouse with average collection efficiency >99%. Factor represents emissions of lead oxide that escape a baghouse used to collect the lead oxide product. Represents approximate upper limit for emissions.

EMISSION FACTORS

so2 Particulateb Lead^b EMISSION **EMISSION** EMISSION EMISSION EMISSION FACTOR FACTOR FACTOR FACTOR FACTOR Uncontrolled RATING Uncontrolled RATING Controlled RATING Uncontrolled RATING Controlled RATING Process Sweating^c (kg/Mg charge) Ē 7-16^d Ε ND NA ND NA 32-70 ND NA (SCC 3-04-004-04) С С NA С Reverberatory smelting 323 С 1.01 65 ND 80 $(71-88)^{f}$ (0.53-1.55)^f (SCC 3-04-004-02) (173-483)^e (35-97)^g С 53 С Blast smelting-cupolah С 104 С 0.29 307 С 2.24 $(0.22-4.88)^{k}$ $(0.03-0.64)^{n}$ (18-110)^e (SCC 3-04-004-03) $(184-413)^{j}$ $(64-140)^{m}$ ND NA 0.03P С ND 0.01^p С ND NA Kettle refining NA (SCC 3-04-004-26) ND NA Ε ND NA ND NA ND NA Kettle Oxidation $< 40^{p}$ (SCC 3-04-004-08) ND NA С ND Casting (SCC 3-04-004-09) 0.04P С ND NA 0.01^p NA

Table 12.11-2 (English Units). EMISSION FACTORS FOR SECONDARY LEAD PROCESSING^a

^a Emission factors expressed as lb of pollutant/ton of metal produced. SCC = Source Classification Code. ND = no data. NA = not applicable.

^o Particulate and lead emission factors are based on quantity of lead product produced, except as noted.

^c Reference 1. Estimated from sweating furnace emissions from nonlead secondary nonferrous processing industries.

^d References 3,5. Based on assumption that uncontrolled reverberatory furnace flue emissions are 23% lead.

- ^e References 8-11.
- f References 6,8-11.
- ^g Reference 13. Uncontrolled reverberatory furnace flue emissions assumed to be 23% lead. Blast furnace emissions have lead content of 34%, based on single uncontrolled plant test.

^h Blast furnace emissions are combined flue gases and associated ventilation hood streams (charging and tapping).

^j References 8,11-12.

^k References 6,8,11-12,14-15.

^m Reference 13. Blast furnace emissions have lead content of 26%, based on single controlled plant test.

- ⁿ Based on quantity of material charged to furnaces.
- ^p Reference 13. Lead content of kettle refining emissions is 40% and of casting emissions is 36%.
- ⁹ References 1-2. Essentially all product lead oxide is entrained in an air stream and subsequently recovered by baghouse with average collection efficiency >99%. Factor represents emissions of lead oxide that escape a baghouse used to collect the lead oxide product. Represents approximate upper limit for emissions.

Table 12.11-3 (Metric Units). FUGITIVE EMISSION FACTORS FOR SECONDARY LEAD PROCESSING^a

EMISSION FACTOR RATING: E

Operation	Particulate	Lead
Sweating (SCC 3-04-004-12)	0.8-1.8 ^b	0.2-0.9°
Smelting (SCC 3-04-004-13)	4.3-12.1	0.1-0.3 ^d
Kettle refining (SCC 3-04-004-14)	0.001	0.0003 ^e
Casting (SCC 3-04-004-25)	0.001	0.0004 ^e

^a Reference 16. Based on amount of lead product except for sweating, which is based on quantity of material charged to furnace. Fugitive emissions estimated to be 5% of uncontrolled stack emissions. SCC= Source Classification Code.

^b Reference 1. Sweating furnace emissions estimated from nonlead secondary nonferrous processsing industries.

^c References 3,5. Assumes 23% lead content of uncontrolled blast furnace flue emissions.

^d Reference 24.

^e Reference 13.

Table 12.11-4 (English Units). FUGITIVE EMISSION FACTORS FOR SECONDARY LEAD PROCESSING^a

EMISSION FACTOR RATING: E

Operation	Particulate	Lead
Sweating (SCC 3-04-004-12)	1.6-3.5 ^b	0.4-1.8°
Smelting (SCC 3-04-004-13)	8.6-24.2	0.2-0.6 ^d
Kettle refining (SCC 3-04-004-14)	0.002	0.0006 ^e
Casting (SCC 3-04-004-25)	0.002	0.0007 ^e

^a Reference 16. Based on amount of lead product, except for sweating, which is based on quantity of material charged to furnace. Fugitive emissions estimated to be 5% of uncontrolled stack emissions. SCC = Source Classification Code.

^b Reference 1. Sweating furnace emissions estimated from nonlead secondary nonferrous processsing industries.

EMISSION FACTORS

^c References 3,5. Assumes 23% lead content of uncontrolled blast furnace flue emissions.

^d Reference 24.

^e Reference 13.

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Emissions from battery breaking are mainly of sulfuric acid mist and dusts containing dirt, battery case material, and lead compounds. Emissions from crushing are also mainly dusts.

Emissions from sweating operations are fume, dust, soot particles, and combustion products, including sulfur dioxide (SO₂). The SO₂ emissions come from combustion of sulfur compounds in the scrap and fuel. Dust particles range in size from 5 to 20 micrometers (μ m) and unagglomerated lead fumes range in size from 0.07 to 0.4 μ m, with an average diameter of 0.3 μ m. Particulate loadings in the stack gas from reverberatory sweating range from 3.2 to 10.3 grams per cubic meter (1.4 to 4.5 grains per cubic foot). Baghouses are usually used to control sweating emissions, with removal efficiencies exceeding 99 percent. The emission factors for lead sweating in Tables 12.11-1 and 12.11-2 are based on measurements at similar sweating furnaces in other secondary metal processing industries, not on measurements at lead sweating furnaces.

Reverberatory smelting furnaces emit particulate and oxides of sulfur and nitrogen. Particulate consists of oxides, sulfides and sulfates of lead, antimony, arsenic, copper, and tin, as well as unagglomerated lead fume. Particulate loadings range from to 16 to 50 grams per cubic meter (7 to 22 grains per cubic foot). Emissions are generally controlled with settling and cooling chambers, followed by a baghouse. Control efficiencies generally exceed 99 percent. Wet scrubbers are sometimes used to reduce SO_2 emissions. However, because of the small particles emitted from reverberatory furnaces, baghouses are more often used than scrubbers for particulate control.

Two chemical analyses by electron spectroscopy have shown the particulate to consist of 38 to 42 percent lead, 20 to 30 percent tin, and about 1 percent zinc.¹⁷ Particulate emissions from reverberatory smelting furnaces are estimated to contain 20 percent lead.

Emissions from blast furnaces occur at charging doors, the slag tap, the lead well, and the furnace stack. The emissions are combustion gases (including carbon monoxide, hydrocarbons, and oxides of sulfur and nitrogen) and particulate. Emissions from the charging doors and the slag tap are hooded and routed to the devices treating the furnace stack emissions. Blast furnace particulate is smaller than that emitted from reverberatory furnaces and is suitable for control by scrubbers or fabric filters downstream of coolers. Efficiencies for various control devices are shown in Table 12.11-5. In one application, fabric filters alone captured over 99 percent of the blast furnace particulate emissions.

Particulate recovered from the uncontrolled flue emissions at 6 blast furnaces had an average lead content of 23 percent.^{3,5} Particulate recovered from the uncontrolled charging and tapping hoods at 1 blast furnace had an average lead content of 61 percent.¹³ Based on relative emission rates, lead is 34 percent of uncontrolled blast furnace emissions. Controlled emissions from the same blast furnace had lead content of 26 percent, with 33 percent from flues, and 22 percent from charging and tapping operations.¹³ Particulate recovered from another blast furnace contained 80 to 85 percent lead sulfate and lead chloride, 4 percent tin, 1 percent cadmium, 1 percent zinc, 0.5 percent antimony, 0.5 percent arsenic, and less than 1 percent organic matter.¹⁸

Kettle furnaces for melting, refining, and alloying are relatively minor emission sources. The kettles are hooded, with fumes and dusts typically vented to baghouses and recovered at efficiencies exceeding 99 percent. Twenty measurements of the uncontrolled particulates from kettle furnaces showed a mass median aerodynamic particle diameter of 18.9 micrometers, with particle size ranging from 0.05 to 150 micrometers. Three chemical analyses by electron spectroscopy showed the composition of particulate to vary from 12 to 17 percent lead, 5 to 17 percent tin, and 0.9 to 5.7 percent zinc.¹⁶

Table 12.11-5. EFFICIENCIES OF PARTICULATE CONTROL EQUIPMENTASSOCIATED WITH SECONDARY LEAD SMELTING FURNACES

Control Equipment	Furnace Type	Control Efficiency (%)
Fabric filter ^a	Blast Blast Reverberatory	98.4 99.2
Dry cyclone plus fabric filter ^a	Blast	99.0
Wet cyclone plus fabric filter ^b	Reverberatory	99.7
Settling chamber plus dry cyclone plus fabric filter ^c	Reverberatory	99.8
Venturi scrubber plus demister ^d	Blast	99.3

^a Reference 8.

^b Reference 9.

^c Reference 10.

^d Reference 14.

Emissions from oxidizing furnaces are economically recovered with baghouses. The particulates are mostly lead oxide, but they also contain amounts of lead and other metals. The oxides range in size from 0.2 to 0.5 μ m. Controlled emissions have been estimated to be 0.1 kilograms per megagram (0.2 pounds per ton) of lead product, based on a 99 percent efficient baghouse.

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12.12 Secondary Magnesium Smelting

12.12.1 General^{1,2}

Secondary magnesium smelters process scrap which contains magnesium to produce magnesium alloys. Sources of scrap for magnesium smelting include automobile crankcase and transmission housings, beverage cans, scrap from product manufacture, and sludges from various magnesium-melting operations. This form of recovery is becoming an important factor in magnesium production. In 1983, only 13 percent of the U. S. magnesium supply came from secondary production; in 1991, this number increased to 30 percent, primarily due to increased recycling of beverage cans.

12.12.2 Process Description^{3,4}

Magnesium scrap is sorted and charged into a steel crucible maintained at approximately 675°C (1247°F). As the charge begins to burn, flux must be added to control oxidation. Fluxes usually contain chloride salts of potassium, magnesium, barium, and magnesium oxide and calcium fluoride. Fluxes are floated on top of the melt to prevent contact with air. The method of heating the crucible causes the bottom layer of scrap to melt first while the top remains solid. This semi-molten state allows cold castings to be added without danger of "shooting", a violent reaction that occurs when cold metals are added to hot liquid metals. As soon as the surface of the feed becomes liquid, a crusting flux must be added to inhibit surface burning.

The composition of the melt is carefully monitored. Steel, salts, and oxides coagulate at the bottom of the furnace. Additional metals are added as needed to reach specifications. Once the molten metal reaches the desired levels of key components, it is poured, pumped, or ladled into ingots.

12.12.3 Emissions And Controls^{5,6}

Emissions for a typical magnesium smelter are given in Tables 12.12-1 and 12.12-2. Emissions from magnesium smelting include particulate magnesium oxides (MgO) and from the melting and fluxing processes, and nitrogen oxides from the fixation of atmospheric nitrogen by the furnace temperatures. Carbon monoxide and nonmethane hydrocarbons have also been detected. The type of flux used on the molten material, the amount of contamination of the scrap (especially oil and other hydrocarbons), and the type and extent of control equipment affect the amount of emissions produced.

Table 12.12-1 (Metric Units). EMISSION FACTORS FOR SECONDARY MAGNESIUM SMELTING

Type of Furnace	Particulate Emission Factor ^a	EMISSION FACTOR RATING
Pot Furnace (SCC 3-04-006-01)		
Uncontrolled	2	С
Controlled	0.2	С

^a References 5 and 6. Emission factors are expressed as kg of pollutant/Mg of metal processed. SCC = Source Classification Code.

Table 12.12-2 (English Units).EMISSION FACTORS FOR
SECONDARY MAGNESIUM SMELTING

Type of Furnace	Particulate Emission Factor ^a	EMISSION FACTOR RATING
Pot Furnace (SCC 3-04-006-01)		
Uncontrolled	4	С
Controlled	0.4	С

^a References 5 and 6. Emission factors are expressed as lb of pollutant/ton of metal processed. SCC = Source Classification Code.

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12.13 Steel Foundries

12.13.1 General

Steel foundries produce steel castings weighing from a few ounces to over 180 megagrams (Mg) (200 tons). These castings are used in machinery, transportation, and other industries requiring parts that are strong and reliable. In 1989, 1030 million Mg (1135 million tons) of steel (carbon and alloy) were cast by U. S. steel foundries, while demand was calculated at 1332 Mg (1470 million tons). Imported steel accounts for the difference between the amount cast and the demand amount. Steel casting is done by small- and medium-size manufacturing companies.

Commercial steel castings are divided into 3 classes: (1) carbon steel, (2) low-alloy steel, and (3) high-alloy steel. Different compositions and heat treatments of steel castings result in a tensile strength range of 400 to 1700 MPa (60,000 to 250,000 psi).

12.13.2 Process Description¹

Steel foundries produce steel castings by melting scrap, alloying, molding, and finishing. The process flow diagram of a typical steel foundry with fugitive emission points is presented in Figure 12.13-1. The major processing operations of a typical steel foundry are raw materials handling, metal melting, mold and core production, and casting and finishing.

12.13.2.1 Raw Materials Handling -

Raw material handling operations include receiving, unloading, storing, and conveying all raw materials for the foundry. Some of the raw materials used by steel foundries are iron and steel scrap, foundry returns, metal turnings, alloys, carbon additives, fluxes (limestone, soda ash, fluorspar, calcium carbide), sand, sand additives, and binders. These raw materials are received in ships, railcars, trucks, and containers, and are transferred by trucks, loaders, and conveyors to both openpile and enclosed storage areas. They are then transferred by similar means from storage to the subsequent processes.

12.13.2.2 Metal Melting⁹ -

Metal melting process operations are: (1) scrap preparation; (2) furnace charging, in which metal, scrap, alloys, carbon, and flux are added to the furnace; (3) melting, during which the furnace remains closed; (4) backcharging, which is the addition of more metal and possibly alloys; (5) refining by single (oxidizing) slag or double (oxidizing and reducing) slagging operations; (6) oxygen lancing, which is injecting oxygen into the molten steel to adjust the chemistry of the metal and speed up the melt; and (7) tapping the molten metal into a ladle or directly into molds. After preparation, the scrap, metal, alloy, and flux are weighed and charged to the furnace.

Electric furnaces are used almost exclusively in the steel foundry for melting and formulating steel. There are 2 types of electric furnaces: direct arc and induction.

Electric arc furnaces are charged with raw materials by removing the lid through a chute opening in the lid or through a door in the side. The molten metal is tapped by tilting and pouring through a spout on the side. Melting capacities range up to 10 Mg (11 tons) per hour.



Figure 12.13-1. Flow diagram of a typical steel foundry. (Source Classification Codes in parentheses.)

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A direct electric arc furnace is a large refractory-lined steel pot, fitted with a refractory roof through which 3 vertical graphite electrodes are inserted, as shown in Figure 12.13-2. The metal charge is melted with resistive heating generated by electrical current flowing among the electrodes and through the charge.



Figure 12.13-2. Electric arc steel furnace.

An induction furnace is a vertical refractory-lined cylinder surrounded by coils energized with alternating current. The resulting fluctuating magnetic field heats the metal. Induction furnaces are kept closed except when charging, skimming, and tapping. The molten metal is tapped by tilting and pouring through a spout on the side. Induction furnaces are also used in conjunction with other furnaces, to hold and superheat a charge, previously melted and refined in another furnace. A very small fraction of the secondary steel industry also uses crucible and pneumatic converter furnaces. A less common furnace used in steel foundries is the open hearth furnace, a very large shallow refractory-lined batch operated vessel. The open hearth furnace is fired at alternate ends, using the hot waste combustion gases to heat the incoming combustion air.

12.13.2.3 Mold And Core Production -

Cores are forms used to make the internal features in castings. Molds are forms used to shape the casting exterior. Cores are made of sand with organic binders, molded into a core and baked in an oven. Molds are made of sand with clay or chemical binders. Increasingly, chemical

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binders are being used in both core and mold production. Used sand from castings shakeout operations is usually recycled to the sand preparation area, where it is cleaned, screened, and reused.

12.13.2.4 Casting And Finishing -

When the melting process is complete, the molten metal is tapped and poured into a ladle. The molten metal may be treated in the ladle by adding alloys and/or other chemicals. The treated metal is then poured into molds and allowed to partially cool under carefully controlled conditions. When cooled, the castings are placed on a vibrating grid and the sand of the mold and core are shaken away from the casting.

In the cleaning and finishing process, burrs, risers, and gates are broken or ground off to match the contour of the casting. Afterward, the castings can be shot-blasted to remove remaining mold sand and scale.

12.13.3 Emissions And Controls^{1,16}

Emissions from the raw materials handling operations are fugitive particulates generated from receiving, unloading, storing, and conveying all raw materials for the foundry. These emissions are controlled by enclosing the major emission points and routing the air from the enclosures through fabric filters.

Emissions from scrap preparation consist of hydrocarbons if solvent degreasing is used and consist of smoke, organics, and carbon monoxide (CO) if heating is used. Catalytic incinerators and afterburners of approximately 95 percent control efficiency for carbon monoxide and organics can be applied to these sources.

Emissions from melting furnaces are particulates, carbon monoxide, organics, sulfur dioxide, nitrogen oxides, and small quantities of chlorides and fluorides. The particulates, chlorides, and fluorides are generated by the flux. Scrap contains volatile organic compounds (VOCs) and dirt particles, along with oxidized phosphorus, silicon, and manganese. In addition, organics on the scrap and the carbon additives increase CO emissions. There are also trace constituents such as nickel, hexavalent chromium, lead, cadmium, and arsenic. The highest concentrations of furnace emissions occur when the furnace lids and doors are opened during charging, backcharging, alloying, oxygen lancing, slag removal, and tapping operations. These emissions escape into the furnace building and are vented through roof vents. Controls for emissions during the melting and refining operations focus on venting the furnace gases and fumes directly to an emission collection duct and control system. Controls for fugitive furnace emissions involve either the use of building roof hoods or special hoods near the furnace doors, to collect emissions and route them to emission control systems. Emission control systems commonly used to control particulate emissions from electric arc and induction furnaces are bag filters, cyclones, and venturi scrubbers. The capture efficiencies of the collection systems are presented in Tables 12.13-1 and 12.13-2. Usually, induction furnaces are uncontrolled.

Molten steel is tapped from a furnace into a ladle. Alloying agents can be added to the ladle. These include aluminum, titanium, zirconium, vanadium, and boron. Ferroalloys are used to produce steel alloys and adjust the oxygen content while the molten steel is in the ladle. Emissions consist of iron oxides during tapping in addition to oxide fumes from alloys added to the ladle.

The major pollutant from mold and core production are particulates from sand reclaiming, sand preparation, sand mixing with binders and additives, and mold and core forming. Particulate,

Process	Filterable Particulate ^a (TSP)	EMISSION FACTOR RATING	Nitrogen Oxides	EMISSION FACTOR RATING	Filterable PM-10	EMISSION FACTOR RATING
Melting						
Electric arc ^{b,c} (SCC 3-04-007-01)	6.5 (2 to 20)	Е	0.1	E	ND	NA
Open hearth ^{d,e} (SCC 3-04-007-02)	5.5 (1 to 10)	Е	0.005	Е	ND	NA
Open hearth oxygen lanced ^{f,g} (SCC 3-04-007-03)	5 (4 to 5.5)	E	ND	NA	ND	NA
Electric induction ^h (SCC 3-04-007-05)	0.05	Е	ND	NA	0.045	Е
Sand grinding/handling in mold and core making ⁱ (SCC 3-04-007-06)	ND	NA	NA	NA	0.27 ^k 3.0	E E
Core ovens ^j (SCC 3-04-007-07)	ND	NA	ND	NA	1.11 ^k 0.45	E E
Pouring and casting ^j (SCC 3-04-007-08)	ND	NA	ND	NA	1.4	Е
Casting cleaning ^j (SCC 3-04-007-11)	ND	NA	NA	ŅA	0.85	Е
Charge handling ^j (SCC 3-04-007-12)	ND	NA	NA	NA	0.18	Е
Casting cooling ^j (SCC 3-04-007-13)	ND	NA	NA	NA	0.7	Е

^a Expressed as kg/Mg of metal processed. If the scrap metal is very dirty or oily, or if increased oxygen lancing is employed, the emission factor should be chosen from the high side of the factor range. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Electrostatic precipitator, 92 to 98% control efficiency; baghouse (fabric filter), 98 to 99% control efficiency; venturi scrubber, 94 to 98% control efficiency.

^c References 2-7.

^d Electrostatic precipitator, 95 to 98% control efficiency; baghouse, 99.9% control efficiency; venturi scrubber, 96 to 99% control efficiency. ^e References 2,8-10.

^f Electrostatic precipitator, 95 to 98% control efficiency; baghouse, 99% control efficiency; venturi scrubber, 95 to 98% control efficiency.

^g References 5,11.

^h Usually not controlled.

^j Reference 13.

^k Emission factor expressed as kg of pollutant/Mg of sand handled.

Table 12.13-2 (English Units). EMISSION FACTORS FOR STEEL FOUNDRIES

Process	Filterable Particulate ^a	EMISSION FACTOR RATING	Nitrogen Oxides	EMISSION FACTOR RATING	Filterable PM-10	EMISSION FACTOR RATING
Melting						
Electric arc ^{b,c} (SCC 3-04-007-01)	13 (4 to 40)	Е	0.2	Е	ND	NA
Open hearth ^{d,e} (SCC 3-04-007-02)	11 (2 to 20)	Е	0.01	Е	ND	NA
Open hearth oxygen lanced ^{f,g} (SCC 3-04-007-03)	10 (8 to 11)	Е	ND	NA	ND	NA
Electric induction ^h (SCC 3-04-007-05)	0.1	Е	ND	NA	0.09	E
Sand grinding/handling in mold and core making ⁱ (SCC 3-04-007-06)	ND	NA	NA	NA	0.54 ^k 6.0	E E
Core ovens ⁱ (SCC 3-04-007-07)	ND	NA	ND	NA	2.22 ^k 0.90	E E
Pouring and casting ⁱ (SCC 3-04-007-08)	ND	NA	ND	NA	2.8	Е
Casting cleaning ^j (SCC 3-04-007-11)	ND	NA	NA	NA	1.7	Е
Charge handling ^j (SCC 3-04-007-12)	ND	NA	NA	NA	0.36	Е
Casting cooling ^j (SCC 3-04-007-13)	ND	NA	NA	NA	1.4	Е

^a Expressed as lb/ton of metal processed. If the scrap metal is very dirty or oily, or if increased oxygen lancing is employed, the emission factor should be chosen from the high side of the factor range. SCC = Source Classification Code.

^b Electrostatic precipitator, 92 to 98% control efficiency; baghouse (fabric filter), 98 to 99% control efficiency; venturi scrubber, 94 to 98% control efficiency.

^c References 2-7.

^d Electrostatic precipitator, 95 to 98% control efficiency; baghouse , 99.9% control efficiency; venturi scrubber, 96 to 99% control efficiency.

^e References 2,8-10.

^f Electrostatic precipitator, 95 to 98% control efficiency; baghouse, 99% control efficiency; venturi scrubber, 95 to 98% control efficiency.

^g References 5,11.

^h Usually not controlled.

^j Reference 13.

^k Emission factor expressed as lb of pollutant/ton of sand handled.

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VOC, and CO emissions result from core baking and VOC emissions occur during mold drying. Bag filters and scrubbers can be used to control particulates from mold and core production. Afterburners and catalytic incinerators can be used to control VOC and CO emissions.

During casting operations, large quantities of particulates can be generated in the steps prior to pouring. Emissions from pouring consist of fumes, CO, VOCs, and particulates from the mold and core materials when contacted by the molten steel. As the mold cools, emissions continue. A significant quantity of particulate emissions is generated during the casting shakeout operation. The particulate emissions from the shakeout operations can be controlled by either high-efficiency cyclone separators or bag filters. Emissions from pouring are usually uncontrolled.

Emissions from finishing operations consist of particulates resulting from the removal of burrs, risers, and gates and during shot blasting. Particulates from finishing operations can be controlled by cyclone separators.

Nonfurnace emissions sources in steel foundries are very similar to those in iron foundries. Nonfurnace emissions factors and particle size distributions for iron foundry emission sources for criteria and toxic pollutants are presented in Section 12.10, "Gray Iron Foundries".

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12.14 Secondary Zinc Processing

12.14.1 General¹

The secondary zinc industry processes scrap metals for the recovery of zinc in the form of zinc slabs, zinc oxide, or zinc dust. There are currently 10 secondary zinc recovery plants operating in the U. S., with an aggregate capacity of approximately 60 megagrams (60 tons) per year.

12.14.2 Process Description²⁻³

Zinc recovery involves 3 general operations performed on scrap, pretreatment, melting, and refining. Processes typically used in each operation are shown in Figure 12.14-1.

12.14.2.1 Scrap Pretreatment -

Scrap metal is delivered to the secondary zinc processor as ingots, rejected castings, flashing, and other mixed metal scrap containing zinc. Scrap pretreatment includes: (1) sorting, (2) cleaning, (3) crushing and screening, (4) sweating, and (5) leaching.

In the sorting operation, zinc scrap is manually separated according to zinc content and any subsequent processing requirements. Cleaning removes foreign materials to improve product quality and recovery efficiency. Crushing facilitates the ability to separate the zinc from the contaminants. Screening and pneumatic classification concentrates the zinc metal for further processing.

A sweating furnace (rotary, reverberatory, or muffle furnace) slowly heats the scrap containing zinc and other metals to approximately 364°C (687°F). This temperature is sufficient to melt zinc but is still below the melting point of the remaining metals. Molten zinc collects at the bottom of the sweat furnace and is subsequently recovered. The remaining scrap metal is cooled and removed to be sold to other secondary processors.

Leaching with sodium carbonate solution converts dross and skimmings to zinc oxide, which can be reduced to zinc metal. The zinc-containing material is crushed and washed with water, separating contaminants from zinc-containing metal. The contaminated aqueous stream is treated with sodium carbonate to convert zinc chloride into sodium chloride (NaCl) and insoluble zinc hydroxide $[Zn(OH)_2]$. The NaCl is separated from the insoluble residues by filtration and settling. The precipitate zinc hydroxide is dried and calcined (dehydrated into a powder at high temperature) to convert it into crude zinc oxide (ZnO). The ZnO product is usually refined to zinc at primary zinc smelters. The washed zinc-containing metal portion becomes the raw material for the melting process.

12.14.2.2 Melting -

Zinc scrap is melted in kettle, crucible, reverberatory, and electric induction furnaces. Flux is used in these furnaces to trap impurities from the molten zinc. Facilitated by agitation, flux and impurities float to the surface of the melt as dross, and is skimmed from the surface. The remaining molten zinc may be poured into molds or transferred to the refining operation in a molten state.





12.14-2

Zinc alloys are produced from pretreated scrap during sweating and melting processes. The alloys may contain small amounts of copper, aluminum, magnesium, iron, lead, cadmium, and tin. Alloys containing 0.65 to 1.25 percent copper are significantly stronger than unalloyed zinc.

12.14.2.3 Refining -

Refining processes remove further impurities in clean zinc alloy scrap and in zinc vaporized during the melt phase in retort furnaces, as shown in Figure 12.14-2. Molten zinc is heated until it vaporizes. Zinc vapor is condensed and recovered in several forms, depending upon temperature, recovery time, absence or presence of oxygen, and equipment used during zinc vapor condensation. Final products from refining processes include zinc ingots, zinc dust, zinc oxide, and zinc alloys.

Distillation retorts and furnaces are used either to reclaim zinc from alloys or to refine crude zinc. Bottle retort furnaces consist of a pear-shaped ceramic retort (a long-necked vessel used for distillation). Bottle retorts are filled with zinc alloys and heated until most of the zinc is vaporized, sometimes as long as 24 hours. Distillation involves vaporization of zinc at temperatures from 982 to 1249°C (1800 to 2280°F) and condensation as zinc dust or liquid zinc. Zinc dust is produced by vaporization and rapid cooling, and liquid zinc results when the vaporous product is condensed slowly at moderate temperatures. The melt is cast into ingots or slabs.

A muffle furnace, as shown in Figure 12.14-3, is a continuously charged retort furnace, which can operate for several days at a time. Molten zinc is charged through a feed well that also acts as an airlock. Muffle furnaces generally have a much greater vaporization capacity than bottle retort furnaces. They produce both zinc ingots and zinc oxide of 99.8 percent purity.

Pot melting, unlike bottle retort and muffle furnaces, does not incorporate distillation as a part of the refinement process. This method merely monitors the composition of the intake to control the composition of the product. Specified die-cast scraps containing zinc are melted in a steel pot. Pot melting is a simple indirect heat melting operation where the final alloy cast into zinc alloy slabs is controlled by the scrap input into the pot.

Furnace distillation with oxidation produces zinc oxide dust. These processes are similar to distillation without the condenser. Instead of entering a condenser, the zinc vapor discharges directly into an air stream leading to a refractory-lined combustion chamber. Excess air completes the oxidation and cools the zinc oxide dust before it is collected in a fabric filter.

Zinc oxide is transformed into zinc metal though a retort reduction process using coke as a reducing agent. Carbon monoxide produced by the partial oxidation of the coke reduces the zinc oxide to metal and carbon dioxide. The zinc vapor is recovered by condensation.

12.14.3 Emissions And Controls²⁻⁵

Process and fugitive emission factors for secondary zinc operations are tabulated in Tables 12.14-1, 12.14-2, 12.14-3, and 12.14-4. Emissions from sweating and melting operations consist of particulate, zinc fumes, other volatile metals, flux fumes, and smoke generated by the incomplete combustion of grease, rubber, and plastics in zinc scrap. Zinc fumes are negligible at low furnace temperatures. Flux emissions may be minimized by using a nonfuming flux. In production requiring special fluxes that do generate fumes, fabric filters may be used to collect emissions. Substantial emissions may arise from incomplete combustion of carbonaceous material in the zinc scrap. These contaminants are usually controlled by afterburners.



Figure 12.14-2. Zinc retort distillation furnace.



Figure 12.14-3. Muffle furnace and condenser.

EMISSION FACTORS

Operation	Emissions	EMISSION FACTOR RATING
Reverberatory sweating ^b (in mg/Mg feed material) Clean metallic scrap (SCC 3-04-008-18) General metallic scrap (SCC 3-04-008-28) Residual scrap (SCC 3-04-008-38)	Negligible 6.5 16	с с с
Rotary sweating ^c (SCC 3-04-008-09)	5.5 - 12.5	с
Muffle sweating ^c (SCC 3-04-008-10)	5.4 - 16	с
Kettle sweating ^b Clean metallic scrap (SCC 3-04-008-14) General metallic scrap (SCC 3-04-008-24) Residual scrap (SCC 3-04-008-34)	Negligible 5.5 12.5	C C C
Electric resistance sweating ^c (SCC 3-04-008-11)	< 5	С
Sodium carbonate leaching calcining ^d (SCC 3-04-008-06)	44.5	С
Kettle pot ^d , mg/Mg product (SCC 3-04-008-03)	0.05	С
Crucible melting (SCC 3-04-008-41)	ND	NA
Reverberatory melting (SCC 3-04-008-42)	ND	NA
Electric induction melting (SCC 3-04-008-43)	ND	NA
Alloying (SCC 3-04-008-40)	ND	NA
Retort and muffle distillation, in kg/Mg of product Pouring ^c (SCC 3-04-008-51) Casting ^c (SCC 3-04-008-52) Muffle distillation ^d (SCC 3-04-008-02)	0.2 - 0.4 0.1 - 0.2 22.5	C C C
Graphite rod distillation ^{c,e} (SCC 3-04-008-53)	Negligible	С
Retort distillation/oxidation ^f (SCC 3-04-008-54)	10 - 20	с
Muffle distillation/oxidation ^f (SCC 3-04-008-55)	10 - 20	С
Retort reduction (SCC 3-04-008-01)	23.5	С
Galvanizing ^d (SCC 3-04-008-05)	2.5	С

Table 12.14-1 (Metric Units). UNCONTROLLED PARTICULATE EMISSION FACTORS FOR SECONDARY ZINC SMELTING^a

^a Factors are for kg/Mg of zinc used, except as noted. SCC = Source Classification Code.
 ND = no data. NA = not applicable.

 ^f Reference 5. Factors are for kg/Mg of ZnO produced. All product zinc oxide dust is carried over in the exhaust gas from the furnace and is recovered with 98 - 99% efficiency.

^b Reference 4.

^c Reference 5.

^d References 6-8.

^e Reference 2.

Table 12.14-2 (English Units). UNCONTROLLED PARTICULATE EMISSION FACTORS FOR SECONDARY ZINC SMELTING^a

		EMISSION FACTOR
Operation	Emissions	RATING
Reverberatory sweating ^b (in mg/Mg feed material) Clean metallic scrap (SCC 3-04-008-18) General metallic scrap (SCC 3-04-008-28) Residual scrap (SCC 3-04-008-38)	Negligible 13 32	C C C
Rotary sweating ^c (SCC 3-04-008-09)	11 - 25	С
Muffle sweating ^c (SCC 3-04-008-10)	10.8 - 32	С
Kettle sweating ^b Clean metallic scrap (SCC 3-04-008-14) General metallic scrap (SCC 3-04-008-24) Residual scrap (SCC 3-04-008-34)	Negligible 11 25	C C C
Electric resistance sweating ^c (SCC 3-04-008-11)	< 10	С
Sodium carbonate leaching calcining ^d (SCC 3-04-008-06)	89	С
Kettle pot ^d , mg/Mg product (SCC 3-04-008-03)	0.1	С
Crucible melting (SCC 3-04-008-41)	ND	NA
Reverberatory melting (SCC 3-04-008-42)	ND	NA
Electric induction melting (SCC 3-04-008-43)	ND	NA
Alloying (SCC 3-04-008-40)	ND	NA
Retort and muffle distillation, in lb/ton of product Pouring ^c (SCC 3-04-008-51) Casting ^c (SCC 3-04-008-52) Muffle distillation ^d (SCC 3-04-008-02)	0.4 - 0.8 0.2 - 0.4 45	C C C
Graphite rod distillation ^{c,e} (SCC 3-04-008-53)	Negligible	С
Retort distillation/oxidation ^f (SCC 3-04-008-54)	20 - 40	С
Muffle distillation/oxidation ^f (SCC 3-04-008-55)	20 - 40	С
Retort reduction (SCC 3-04-008-01)	47	C
Galvanizing ^d (SCC 3-04-008-05)	5	C

^a Factors are for lb/ton of zinc used, except as noted. SCC = Source Classification Code.

ND = no data. NA = not applicable.

^f Reference 5. Factors are for lb/ton of ZnO produced. All product zinc oxide dust is carried over in the exhaust gas from the furnace and is recovered with 98 - 99% efficiency.

^b Reference 4.

^c Reference 5.

^d References 6-8.

^e Reference 2.

Operation	Emissions	EMISSION FACTOR RATING
Reverberatory sweating ^b (SCC 3-04-008-61)	0.63	E
Rotary sweating ^b (SCC 3-04-008-62)	0.45	Е
Muffle sweating ^b (SCC 3-04-008-63)	0.54	E
Kettle (pot) sweating ^b (SCC 3-04-008-64)	0.28	Е
Electrical resistance sweating, per kg processed ^b (SCC 3-04-008-65)	0.25	Е
Crushing/screening ^c (SCC 3-04-008-12)	2.13	E
Sodium carbonate leaching (SCC 3-04-008-66)	ND	NA
Kettle (pot) melting furnace ^b (SCC 3-04-008-67)	0.0025	Е
Crucible melting furnace ^d (SCC 3-04-008-68)	0.0025	Е
Reverberatory melting furnace ^b (SCC 3-04-008-69)	0.0025	Ε
Electric induction melting ^b (SCC 3-04-008-70)	0.0025	Е
Alloying retort distillation (SCC 3-04-008-71)	ND	NA
Retort and muffle distillation (SCC 3-04-008-72)	1.18	E
Casting ^b (SCC 3-04-008-73)	0.0075	Е
Graphite rod distillation (SCC 3-04-008-74)	ND	NA
Retort distillation/oxidation (SCC 3-04-008-75)	ND	NA
Muffle distillation/oxidation (SCC 3-04-008-76)	ND	NA
Retort reduction (SCC 3-04-008-77)	ND	NA

Table 12.14-3 (Metric Units). FUGITIVE PARTICULATE EMISSION FACTORS FOR SECONDARY ZINC SMELTING^a

^a Reference 9. Factors are kg/Mg of end product, except as noted. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Estimate based on stack emission factor given in Reference 2, assuming fugitive emissions to be equal to 5% of stack emissions.

^c Reference 2. Factors are for kg/Mg of scrap processed. Average of reported emission factors.

^d Engineering judgment, assuming fugitive emissions from crucible melting furnace to be equal to fugitive emissions from kettle (pot) melting furnace.

Particulate emissions from sweating and melting are most commonly recovered by fabric filter. In 1 application on a muffle sweating furnace, a cyclone and fabric filter achieved particulate recovery efficiencies in excess of 99.7 percent. In 1 application on a reverberatory sweating furnace, a fabric filter removed 96.3 percent of the particulate. Fabric filters show similar efficiencies in removing particulate from exhaust gases of melting furnaces.

Operation	Emissions	EMISSION FACTOR RATING
Reverberatory sweating ^b (SCC 3-04-008-61)	1.30	E
Rotary sweating ^b (SCC 3-04-008-62)	0.90	Е
Muffle sweating ^b (SCC 3-04-008-63)	1.07	Е
Kettle (pot) sweating ^b (SCC 3-04-008-64)	0.56	Е
Electrical resistance sweating, per ton processed ^b (SCC 3-04-008-65)	0.50	E
Crushing/screening ^c (SCC 3-04-008-12)	4.25	E
Sodium carbonate leaching (SCC 3-04-008-66)	ND	NA
Kettle (pot) melting furnace ^b (SCC 3-04-008-67)	0.005	Е
Crucible melting furnace ^d (SCC 3-04-008-68)	0.005	Е
Reverberatory melting furnace ^b (SCC 3-04-008-69)	0.005	E
Electric induction melting ^b (SCC 3-04-008-70)	0.005	Е
Alloying retort distillation (SCC 3-04-008-71)	ND	NA
Retort and muffle distillation (SCC 3-04-008-72)	2.36	Е
Casting ^b (SCC 3-04-008-73)	0.015	Е
Graphite rod distillation (SCC 3-04-008-74)	ND	NA
Retort distillation/oxidation (SCC 3-04-008-75)	ND	NA
Muffle distillation/oxidation (SCC 3-04-008-76)	ND	NA
Retort reduction (SCC 3-04-008-77)	ND	NA

Table 12.14-4 (English Units). FUGITIVE PARTICULATE EMISSION FACTORS FOR SECONDARY ZINC SMELTING^a

 ^a Reference 9. Factors are lb/ton of end product, except as noted. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Estimate based on stack emission factor given in Reference 2, assuming fugitive emissions to be equal to 5% of stack emissions.

^c Reference 2. Factors are for lb/ton of scrap processed. Average of reported emission factors.

^d Engineering judgment, assuming fugitive emissions from crucible melting furnace to be equal to fugitive emissions from kettle (pot) melting furnace.

Crushing and screening operations are also sources of dust emissions. These emissions are composed of zinc, aluminum, copper, iron, lead, cadmium, tin, and chromium. They can be recovered by hooded exhausts used as capture devices and can be controlled with fabric filters.

The sodium carbonate leaching process emits zinc oxide dust during the calcining operation (oxidizing precipitate into powder at high temperature). This dust can be recovered in fabric filters, although zinc chloride in the dust may cause plugging problems.

Emissions from refining operations are mainly metallic fumes. Distillation/oxidation operations emit their entire zinc oxide product in the exhaust gas. Zinc oxide is usually recovered in fabric filters with collection efficiencies of 98 to 99 percent.

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12.15 Storage Battery Production

12.15.1 General¹⁻²

The battery industry is divided into 2 main sectors: starting, lighting, and ignition (SLI) batteries and industrial/traction batteries. SLI batteries are primarily used in automobiles. Industrial batteries include those used for uninterruptible power supply and traction batteries are used to power electric vehicles such as forklifts. Lead consumption in the U. S. in 1989 was 1.28 million megagrams (1.41 million tons); between 75 and 80 percent of this is attributable to the manufacture of lead acid storage batteries.

Lead acid storage battery plants range in production capacity from less than 500 batteries per day to greater than 35,000 batteries per day. Lead acid storage batteries are produced in many sizes, but the majority are produced for use in automobiles and fall into a standard size range. A standard automobile battery contains an average of about 9.1 kilograms (20 lb) of lead, of which about half is present in the lead grids and connectors and half in the lead oxide paste.

12.15.2 Process Description^{3,12}

Lead acid storage batteries are produced from lead alloy ingots and lead oxide. The lead oxide may be prepared by the battery manufacturer, as is the case for many larger battery manufacturing facilities, or may be purchased from a supplier. (See Section 12.16, "Lead Oxide And Pigment Production".)

Battery grids are manufactured by either casting or stamping operations. In the casting operation, lead alloy ingots are charged to a melting pot, from which the molten lead flows into molds that form the battery grids. The stamping operation involves cutting or stamping the battery grids from lead sheets. The grids are often cast or stamped in doublets and split apart (slitting) after they have been either flash dried or cured. The pastes used to fill the battery grids are made in batch-type processes. A mixture of lead oxide powder, water, and sulfuric acid produces a positive paste, and the same ingredients in slightly different proportions with the addition of an expander (generally a mixture of barium sulfate, carbon black, and organics), make the negative paste. Pasting machines then force these pastes into the interstices of the grids, which are made into plates. At the completion of this process, a chemical reaction starts in the paste and the mass gradually hardens, liberating heat. As the setting process continues, needle-shaped crystals of lead sulfate (PbSO₄) form throughout the mass. To provide optimum conditions for the setting process, the plates are kept at a relative humidity near 90 percent and a temperature near $32^{\circ}C$ (90°F) for about 48 hours and are then allowed to dry under ambient conditions.

After the plates are cured they are sent to the 3-process operation of plate stacking, plate burning, and element assembly in the battery case (see Figure 12.15-1). In this process the doublet plates are first cut apart and depending upon whether they are dry-charged or to be wet-formed, are stacked in an alternating positive and negative block formation, with insulators between them. These insulators are made of materials such as non-conductive plastic, or glass fiber. Leads are then welded to tabs on each positive or negative plate or in an element during the burning operation. An alternative to this operation, and more predominantly used than the manual burning operation, is the cast-on connection, and positive and negative tabs are then independently welded to produce an element. The elements are automatically placed into a battery case. A top is placed on the



Figure 12.15-1. Process flow diagram for storage battery production. (Source Classification Codes in parentheses.)

batterycase. The posts on the case top then are welded to 2 individual points that connect the positive and negative plates to the positive and negative posts, respectively.

During dry-charge formation, the battery plates are immersed in a dilute sulfuric acid solution; the positive plates are connected to the positive pole of a direct current (DC) source and the negative plates connected to the negative pole of the DC source. In the wet formation process, this is done with the plates in the battery case. After forming, the acid may be dumped and fresh acid is added, and a boost charge is applied to complete the battery. In dry formation, the individual plates may be assembled into elements first and then formed in tanks or formed as individual plates. In this case of formed elements, the elements are then placed in the battery cases, the positive and negative parts of the elements are connected to the positive and negative terminals of the battery, and the batteries are shipped dry. Defective parts are either reclaimed at the battery plant or are sent to a secondary lead smelter (See Section 12.11, "Secondary Lead Processing"). Lead reclamation facilities at battery plants are generally small pot furnaces for non-oxidized lead. Approximately 1 to 4 percent of the lead processed at a typical lead acid battery plant is recycled through the reclamation operation as paste or metal. In recent years, however, the general trend in the lead-acid battery manufacturing industry has been to send metals to secondary lead smelters for reclamation.

12.15.3 Emissions And Controls^{3-9,13-16}

Lead oxide emissions result from the discharge of air used in the lead oxide production process. A cyclone, classifier, and fabric filter is generally used as part of the process/control equipment to capture particulate emissions from lead oxide facilities. Typical air-to-cloth ratios of fabric filters used for these facilities are in the range of 3:1.

Lead and other particulate matter are generated in several operations, including grid casting, lead reclamation, slitting, and small parts casting, and during the 3-process operation. This particulate is usually collected by ventilation systems and ducted through fabric filtration systems (baghouses) also.

The paste mixing operation consists of 2 steps. The first, in which dry ingredients are charged to the mixer, can result in significant emissions of lead oxide from the mixer. These emissions are usually collected and ducted through a baghouse. During the second step, when moisture is present in the exhaust stream from acid addition, emissions from the paste mixer are generally collected and ducted to either an impingement scrubber or fabric filter. Emissions from grid casting machines and lead reclamation facilities are sometimes processed by impingement scrubbers as well.

Sulfuric acid mist emissions are generated during the formation step. Acid mist emissions are significantly higher for dry formation processes than for wet formation processes because wet formation is conducted in battery cases, while dry formation is conducted in open tanks. Although wet formation process usually do not require control, emissions of sulfuric acid mist from dry formation processes can be reduced by more than 95 percent with mist eliminators. Surface foaming agents are also commonly used in dry formation baths to strap process, in which molten lead is poured around the plate tabs to form the control acid mist emissions.

Emission reductions of 99 percent and above can be obtained when fabric filtration is used to control slitting, paste mixing, and the 3-process operation. Applications of scrubbers to paste mixing, grid casting, and lead reclamation facilities can result in emission reductions of 85 percent or better.

Tables 12.15-1 and 12.15-2 present uncontrolled emission factors for grid casting, paste mixing, lead reclamation, dry formation, and the 3-process operation as well as a range of controlled emission factors for lead oxide production. The emission factors presented in the tables include lead and its compounds, expressed as elemental lead.

Process	Particulate (kg/10 ³ batteries)	Lead (kg/10 ³ batteries)	EMISSION FACTOR RATING
Grid casting (SCC 3-04-005-06)	0.8 - 1.42	0.35 - 0.40	В
Paste mixing (SCC 3-04-005-07)	1.00 - 1.96	0.50 - 1.13	В
Lead oxide mill (baghouse outlet) ^b (SCC 3-04-005-08)	0.05 - 0.10	0.05	С
3-Process operation (SCC 3-04-005-09)	13.2 - 42.00	4.79 - 6.60	В
Lead reclaim furnace ^c (SCC 3-04-005-10)	0.70 - 3.03	0.35 - 0.63	В
Dry formation ^d (SCC 3-04-005-12)	14.0 - 14.70	ND	В
Small parts casting (SCC 3-04-005-11)	0.09	0.05	С
Total production (SCC 3-04-005-05)	56. 82 - 63.20	6.94 - 8.00	NA

Table 12.15-1 (Metric Units). UNCONTROLLED EMISSION FACTORS FOR STORAGE BATTERY PRODUCTION^a

^a References 3-10,13-16. SCC = Source Classification Code. ND = no data. NA = not applicable.

^c Range due to variability of the scrap quality.

^d For sulfates in aerosol form, expressed as sulfuric acid or particulate, and not accounting for water and other substances which might be present.

 ^b Reference 7. Emissions measured for a "state-of-the-art" facility (fabric filters with an average air-to-cloth ratio of 3:1) were 0.025 kg particulate/1000 batteries and 0.024 kg lead/1000 batteries.
 Factors represent emissions from a facility with typical controls (fabric filtration with an air-to-cloth ratio of about 4:1). Emissions from a facility with typical controls are estimated to be about 2-10 times higher than those from a "state-of-the-art" facility (Reference 3).

Table 12.15-2 (English Units).UNCONTROLLED EMISSION FACTORS FOR
STORAGE BATTERY PRODUCTION^a

Process	Particulate (lb/10 ³ batteries)	Lead (lb/10 ³ batteries)	EMISSION FACTOR RATING
Grid casting (SCC 3-04-005-06)	1.8 - 3.13	0.77 - 0.90	В
Paste mixing (SCC 3-04-005-07)	2.20 - 4.32	1.10 - 2.49	В
Lead oxide mill (baghouse outlet) ^b (SCC 3-04-005-08)	0.11 - 0.24	0.11 - 0.12	C
3-Process operation (SCC 3-04-005-09)	29.2 - 92.60	10.60 - 14.60	В
Lead reclaim furnace ^c (SCC 3-04-005-10)	1.54 - 6.68	0.77 - 1.38	В
Dry formation ^d (SCC 3-04-005-12)	32.1 - 32.40	ND	В
Small parts casting (SCC 3-04-005-11)	0.19	0.10	С
Total production (SCC 3-04-005-05)	125.00 - 139.00	15.30 - 17.70	NA

^a References 3-10, 13-16. SCC = Source Classification Code. ND = no data.
 NA = not applicable.

^b Reference 7. Emissions measured for a "state-of-the-art" facility (fabric filters with an average air-to-cloth ratio of 3:1) were 0.055 lb particulate/1000 batteries and 0.053 lb lead/1000 batteries. Factors represent emissions from a facility with typical controls (fabric filtration with an air-to-cloth ratio of about 4:1). Emissions from a facility with typical controls are estimated to be about 2-10 times higher than those from a "state-of-the-art" facility (Reference 3).

^c Range due to variability of the scrap quality.

^d For sulfates in aerosol form, expressed as sulfuric acid, and not accounting for water and other substances which might be present.

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12.16 Lead Oxide And Pigment Production

12.16.1 General^{1-2,7}

Lead oxide is a general term and can be either lead monoxide or "litharge" (PbO); lead tetroxide or "red lead" (Pb_3O_4); or black or "gray" oxide which is a mixture of 70 percent lead monoxide and 30 percent metallic lead. Black lead is made for specific use in the manufacture of lead acid storage batteries. Because of the size of the lead acid battery industry, lead monoxide is the most important commercial compound of lead, based on volume. Total oxide production in 1989 was 57,984 megagrams (64,000 tons).

Litharge is used primarily in the manufacture of various ceramic products. Because of its electrical and electronic properties, litharge is also used in capacitors, Vidicon^{\oplus} tubes, and electrophotographic plates, as well as in ferromagnetic and ferroelectric materials. It is also used as an activator in rubber, a curing agent in elastomers, a sulfur removal agent in the production of thioles and in oil refining, and an oxidation catalyst in several organic chemical processes. It also has important markets in the production of many lead chemicals, dry colors, soaps (i. e., lead stearate), and driers for paint. Another important use of litharge is the production of lead salts, particularly those used as stabilizers for plastics, notably polyvinyl chloride materials.

The major lead pigment is red lead (Pb_3O_4) , which is used principally in ferrous metal protective paints. Other lead pigments include white lead and lead chromates. There are several commercial varieties of white lead including leaded zinc oxide, basic carbonate white lead, basic sulfate white lead, and basic lead silicates. Of these, the most important is leaded zinc oxide, which is used almost entirely as white pigment for exterior oil-based paints.

12.16.2 Process Description⁸

Black oxide is usually produced by a Barton Pot process. Basic carbonate white lead production is based on the reaction of litharge with acetic acid or acetate ions. This product, when reacted with carbon dioxide, will form lead carbonate. White leads (other than carbonates) are made either by chemical, fuming, or mechanical blending processes. Red lead is produced by oxidizing litharge in a reverberatory furnace. Chromate pigments are generally manufactured by precipitation or calcination as in the following equation:

$$Pb(NO_3)_2 + Na_2(CrO_4) \rightarrow PbCrO_4 + 2 NaNO_3$$
(1)

Commercial lead oxides can all be prepared by wet chemical methods. With the exception of lead dioxide, lead oxides are produced by thermal processes in which lead is directly oxidized with air. The processes may be classified according to the temperature of the reaction: (1) low temperature, below the melting point of lead; (2) moderate temperature, between the melting points of lead and lead monoxide; and (3) high temperature, above the melting point of lead monoxide.

12.16.2.1 Low Temperature Oxidation -

Low temperature oxidation of lead is accomplished by tumbling slugs of metallic lead in a ball mill equipped with an air flow. The air flow provides oxygen and is used as a coolant. If some form of cooling were not supplied, the heat generated by the oxidation of the lead plus the mechanical heat of the tumbling charge would raise the charge temperature above the melting point of lead. The ball mill product is a "leady" oxide with 20 to 50 percent free lead.

12.16.2.2 Moderate Temperature Oxidation -

Three processes are used commercially in the moderate temperature range: (1) refractory furnace, (2) rotary tube furnace, and (3) the Barton Pot process. In the refractory furnace process, a cast steel pan is equipped with a rotating vertical shaft and a horizontal crossarm mounted with plows. The plows move the charge continuously to expose fresh surfaces for oxidation. The charge is heated by a gas flame on its surface. Oxidation of the charge supplies much of the reactive heat as the reaction progresses. A variety of products can be manufactured from pig lead feed by varying the feed temperature, and time of furnacing. Yellow litharge (orthorhombic) can be made by cooking for several hours at 600 to 700 °C (1112 to 1292 °F) but may contain traces of red lead and/or free metallic lead.

In the rotary tube furnace process, molten lead is introduced into the upper end of a refractory-lined inclined rotating tube. An oxidizing flame in the lower end maintains the desired temperature of reaction. The tube is long enough so that the charge is completely oxidized when it emerges from the lower end. This type of furnace has been used commonly to produce lead monoxide (tetragonal type), but it is not unusual for the final product to contain traces of both free metallic and red lead.

The Barton Pot process (Figure 12.16-1) uses a cast iron pot with an upper and lower stirrer rotating at different speeds. Molten lead is fed through a port in the cover into the pot, where it is broken up into droplets by high-speed blades. Heat is supplied initially to develop an operating temperature from 370 to 480°C (698 to 896°F). The exothermic heat from the resulting oxidation of the droplets is usually sufficient to maintain the desired temperature. The oxidized product is swept out of the pot by an air stream.

The operation is controlled by adjusting the rate of molten lead feed, the speed of the stirrers, the temperature of the system, and the rate of air flow through the pot. The Barton Pot produces either litharge or leady litharge (litharge with 50 percent free lead). Since it operates at a higher temperature than a ball mill unit, the oxide portion will usually contain some orthorhombic litharge. It may also be operated to obtain almost entirely orthorhombic product.

12.16.2.3 High Temperature Oxidation -

High temperature oxidation is a fume-type process. A very fine particle, high-purity orthorhombic litharge is made by burning a fine stream of molten lead in a special blast-type burner. The flame temperature is around 1200°C (2192°F). The fume is swept out of the chamber by an air stream, cooled in a series of "goosenecks" and collected in a baghouse. The median particle diameter is from 0.50 to 1.0 micrometers, as compared with 3.0 to 16.0 micrometers for lead monoxide manufactured by other methods.

12.16.3 Emissions And Controls^{3-4,6}

Emission factors for lead oxide and pigment production processes are given in Tables 12.16-1 and 12.16-2. The emission factors were assigned an E rating because of high variabilities in test run results and nonisokinetic sampling. Also, since storage battery production facilities produce lead oxide using the Barton Pot process, a comparison of the lead emission factors from both industries has been performed. The lead oxide emission factors from the battery plants were found to be considerably lower than the emission factors from the lead oxide and pigment industry. Since lead battery production plants are covered under federal regulations, one would expect lower emissions from these sources.



Figure 12.16-1. Lead oxide Barton Pot process. (Source Classification Codes in parentheses.)

Automatic shaker-type fabric filters, often preceded by cyclone mechanical collectors or settling chambers, are the common choice for collecting lead oxides and pigments. Control efficiencies of 99 percent are achieved with these control device combinations. Where fabric filters are not appropriate, scrubbers may be used to achieve control efficiencies from 70 to 95 percent. The ball mill and Barton Pot processes of black oxide manufacturing recover the lead product by these 2 means. Collection of dust and fumes from the production of red lead is likewise an economic necessity, since particulate emissions, although small, are about 90 percent lead. Emissions data from the production of white lead pigments are not available, but they have been estimated because of health and safety regulations. The emissions from dryer exhaust scrubbers account for over 50 percent of the total lead emitted in lead chromate production.

	Partic	ulate	Le		
Process	Emissions	EMISSION FACTOR RATING	Emissions	EMISSION FACTOR RATING	References
Lead Oxide Production					
Barton Pot ^b (SCC 3-01-035-06)	0.21 - 0.43	E	0.22	Ε	4,6
Calcining (SCC 3-01-035-07) Baghouse Inlet Baghouse Outlet	7.13 0.032	E E	7.00 0.024	E E	6 6
Pigment Production					
Red lead ^b (SCC 3-01-035-10)	0.5°	В	0.50	В	4,5
White lead ^b (SCC 3-01-035-15)	ND	NA	0.28	В	4,5
Chrome pigments (SCC 3-01-035-20)	ND	NA	0.065	В	4,5

Table 12.16-1 (Metric Units). CONTROLLED EMISSIONS FROM LEAD OXIDE AND PIGMENT PRODUCTION^a

^a Factors are for kg/Mg of product. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Measured at baghouse outlet. Baghouse is considered process equipment.

^c Only PbO and oxygen are used in red lead production, so particulate emissions are assumed to be about 90% lead.

Table 12.16-2 (English Units). CONTROLLED EMISSIONS FROM LEAD OXIDE AND PIGMENT PRODUCTION^a

	Partic	ulate	Le	ead	
Process	Emissions	EMISSION FACTOR RATING	Emissions	EMISSION FACTOR RATING	References
Lead Oxide Production					
Barton Pot ^b (SCC 3-01-035-06)	0.43 - 0.85	Е	0.44	Е	4,6
Calcining (SCC 3-01-035-07) Baghouse Inlet Baghouse Outlet	14.27 0.064	E E	14.00 0.05	E E	6 6
Pigment Production					
Red lead ^b (SCC 3-01-035-10)	1.0 ^c	В	0.90	В	4,5
White lead ^b (SCC 3-01-035-15)	ND	NA	0.55	В	4,5
Chrome pigments (SCC 3-01-035-20)	ND	NA	0.13	В	4,5

^a Factors are for lb/ton of product. SCC = Source Classification Code. ND = no data. NA = not applicable.

^b Measured at baghouse outlet. Baghouse is considered process equipment.

^c Only PbO and oxygen are used in red lead production, so particulate emissions are assumed to be about 90% lead.

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12.17 Miscellaneous Lead Products

12.17.1 General¹

In 1989 the following categories (in decreasing order of lead usage) were significant in the miscellaneous lead products group: ammunition, cable covering, solder, and type metal. However, in 1992, U. S. can manufacturers no longer use lead solder. Therefore, solder will not be included as a miscellaneous lead product in this section. Lead used in ammunition (bullets and shot) and for shot used at nuclear facilities in 1989 was 62,940 megagrams (Mg) (69,470 tons). The use of lead sheet in construction and lead cable sheathing in communications also increased to a combined total of 43,592 Mg (48,115 tons).

12.17.2 Process Description

12.17.2.1 Ammunition And Metallic Lead Products⁸ -

Lead is consumed in the manufacture of ammunition, bearing metals, and other lead products, with subsequent lead emissions. Lead used in the manufacture of ammunition is melted and alloyed before it is cast, sheared, extruded, swaged, or mechanically worked. Some lead is also reacted to form lead azide, a detonating agent. Lead is used in bearing manufacture by alloying it with copper, bronze, antimony, and tin, although lead usage in this category is relatively small.

Other lead products include terne metal (a plating alloy), weights and ballasts, caulking lead, plumbing supplies, roofing materials, casting metal foil, collapsible metal tubes, and sheet lead. Lead is also used for galvanizing, annealing, and plating. In all of these cases lead is usually melted and cast prior to mechanical forming operations.

12.17.2.2 Cable Covering^{8,11} -

About 90 percent of the lead cable covering produced in the United States is lead-cured jacketed cables, the remaining 10 percent being lead sheathed cables. The manufacture of cured jacketed cables involves a stripping/remelt operation as an unalloyed lead cover that is applied in the vulcanizing treatment during the manufacture of rubber-insulated cable must be stripped from the cable and remelted.

Lead coverings are applied to insulated cable by hydraulic extrusion of solid lead around the cable. Extrusion rates of typical presses average 1360 to 6800 Mg/hr (3,000 to 15,000 lb/hr). The molten lead is continuously fed into the extruder or screw press, where it solidifies as it progresses. A melting kettle supplies lead to the press.

12.17.2.3 Type Metal Production⁸ -

Lead type, used primarily in the letterpress segment of the printing industry, is cast from a molten lead alloy and remelted after use. Linotype and monotype processes produce a mold, while the stereotype process produces a plate for printing. All type is an alloy consisting of 60 to 85 percent recovered lead, with antimony, tin, and a small amount of virgin metal.

12.17.3 Emissions And Controls

Tables 12.17-1 and 12.17-2 present emission factors for miscellaneous lead products.

Process	Particulate	EMISSION FACTOR RATING	Lead	EMISSION FACTOR RATING	Reference
Type Metal Production (SCC 3-60-001-01)	0.4 ^b	С	0.13	С	2,7
Cable Covering (SCC 3-04-040-01)	0.3 ^c	с	0.25	с	3,5,7
Metallic Lead Products:				*	
Ammunition (SCC 3-04-051-01)	ND	NA	≤ 0.5	С	3,7
Bearing Metals (SCC 3-04-051-02)	ND	NA	Negligibl e	NA	3,7
Other Sources of Lead (SCC 3-04-051-03)	ND	NA	0.8	с	3,7

Table 12.17-1 (Metric Units). EMISSION FACTORS FOR MISCELLANEOUS SOURCES^a

^a Factors are expressed as kg/Mg lead (Pb) processed. ND = no data. NA = not applicable.

^b Calculated on the basis of 35% of the total (Reference 2). SCC = Source Classification Code.

^c Reference 8, p. 4-301.

Process	Particulate	EMISSION FACTOR RATING	Lead	EMISSION FACTOR RATING	Reference
Type Metal Production	0.7 ^b	с	0.25	с	2,7
Cable Covering (SCC 3-04-040-01)	0.6 ^c	с	0.5	с	3,5,7
Metallic Lead Products:					
Ammunition (SCC 3-04-051-01)	ND	NA	1.0	с	3,7
Bearing Metals (SCC 3-04-051-02)	ND	NA	Negligible	NA	3,7
Other Sources of Lead (SCC 3-04-051-03)	ND	NA	1.5	С	3,7

Table 12.17-2 (English Units). EMISSION FACTORS FOR MISCELLANEOUS SOURCES^a

^a Factors are expressed as lb/ton lead (Pb) processed. ND = no data. NA = not applicable.

^b Calculated on the basis of 35% of the total (Reference 2). SCC = Source Classification Code. ^c Reference 8, p. 4-301.

12.17.3.1 Ammunition And Metallic Lead Products⁸ -

Little or no air pollution control equipment is currently used by manufacturers of metallic lead products. Emissions from bearing manufacture are negligible, even without controls.

12.17.3.2 Cable Covering^{8,11} -

The melting kettle is the only source of atmospheric lead emissions and is generally uncontrolled. Average particle size is approximately 5 micrometers, with a lead content of about 70 to 80 percent.

Cable covering processes do not usually include particulate collection devices. However, fabric filters, rotoclone wet collectors, and dry cyclone collectors can reduce lead emissions at control efficiencies of 99.9 percent, 75 to 85 percent, and greater than 45 percent, respectively. Lowering and controlling the melt temperature, enclosing the melting unit and using fluxes to provide a cover on the melt can also minimize emissions.

12.17.3.3 Type Metal Production^{2,3} -

The melting pot is again the major source of emissions, containing hydrocarbons as well as lead particulates. Pouring the molten metal into the molds involves surface oxidation of the metal, possibly producing oxidized fumes, while the trimming and finishing operations emit lead particles. It is estimated that 35 percent of the total emitted particulate is lead.

Approximately half of the current lead type operations control lead emissions, by approximately 80 percent. The other operations are uncontrolled. The most frequently controlled sources are the main melting pots and drossing areas. Linotype equipment does not require controls when operated properly. Devices in current use on monotype and stereotype lines include rotoclones, wet scrubbers, fabric filters, and electrostatic precipitators, all of which can be used in various combinations.

Additionally, the VOC/PM Speciation Data Base has identified phosphorus, chlorine, chromium, manganese, cobalt, nickel, arsenic, selenium, cadmium, antimony, mercury, and lead as occurring in emissions from type metal production and lead cable coating operations. All of these metals/chemicals are listed in CAA Title III as being hazardous air pollutants (HAPs) and should be the subject of air emissions testing by industry sources.

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12.18 Leadbearing Ore Crushing And Grinding

12.18.1 General¹

Leadbearing ore is mined from underground or open pit mines. After extraction, the ore is processed by crushing, screening, and milling. Domestic lead mine production for 1991 totaled 480,000 megagrams (Mg) (530,000 tons) of lead in ore concentrates, a decrease of some 15,000 Mg (16,500 tons) from 1990 production.

Except for mines in Missouri, lead ore is closely interrelated with zinc and silver. Lead ores from Missouri mines are primarily associated with zinc and copper. Average grades of metal from Missouri mines have been reported as high as 12.2 percent lead, 1 percent zinc, and 0.6 percent copper. Due to ore body formations, lead and zinc ores are normally deep-mined (underground), whereas copper ores are mined in open pits. Lead, zinc, copper, and silver are usually found together (in varying percentages) in combination with sulfur and/or oxygen.

12.18.2 Process Description^{2,5-7}

In underground mines the ore is disintegrated by percussive drilling machines, processed through a primary crusher, and then conveyed to the surface. In open pit mines, ore and gangue are loosened and pulverized by explosives, scooped up by mechanical equipment, and transported to the concentrator. A trend toward increased mechanical excavation as a substitute for standard cyclic mine development, such as drill-and-blast and surface shovel-and-truck routines has surfaced as an element common to most metal mine cost-lowering techniques.

Standard crushers, screens, and rod and ball mills classify and reduce the ore to powders in the 65 to 325 mesh range. The finely divided particles are separated from the gangue and are concentrated in a liquid medium by gravity and/or selective flotation, then cleaned, thickened, and filtered. The concentrate is dried prior to shipment to the smelter.

12.18.3 Emissions And Controls^{2-4,8}

Lead emissions are largely fugitive and are caused by drilling, loading, conveying, screening, unloading, crushing, and grinding. The primary means of control are good mining techniques and equipment maintenance. These practices include enclosing the truck loading operation, wetting or covering truck loads and stored concentrates, paving the road from mine to concentrator, sprinkling the unloading area, and preventing leaks in the crushing and grinding enclosures. Cyclones and fabric filters can be used in the milling operations.

Particulate and lead emission factors for lead ore crushing and materials handling operations are given in Tables 12.18-1 and 12.18-2.

Type Of Ore And Lead Content (wt %)		Particulate Emission Factor ^a	EMISSION FACTOR RATING	Lead Emission Factor ^b	EMISSION FACTOR RATING
Lead ^c (SCC 3-03-031-01)	5.1	3.0	В	0.15	В
Zinc ^d (SCC 3-03-031-02)	0.2	3.0	В	0.006	В
Copper ^e (SCC 3-03-031-03)	0.2	3.2	В	0.006	В
Lead-Zinc ^f (SCC 3-03-031-04)	2.0	3.0	В	0.06	В
Copper-Lead ^g (SCC 3-03-031-05)	2.0	3.2	В	0.06	В
Copper-Zinc ^h (SCC 3-03-031-06)	0.2	3.2	В	0.006	В
Copper-Lead-Zinc ⁱ (SCC 3-03-031-07)	2.0	3.2	В	0.06	В

Table 12.18-1 (Metric Units). EMISSION FACTORS FOR ORE CRUSHING AND GRINDING

^a Reference 2. Units are expressed as kg of pollutant/Mg ore processed. SCC = Source Classification Code.

^b Reference 2,3,5,7.

^c Refer to Section 12.6.

^d Characteristic of some mines in Colorado.

^e Characteristic of some mines in Alaska, Idaho, and New York.

^f Characteristic of Arizona mines.

^g Characteristic of some mines in Missouri, Idaho, Colorado, and Montana.

^h Characteristic of some mines in Missouri.

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ⁱ Does not appear in ore characterization of the top 25 domestic lead producing mines.

Fable 12.18-2 (English Units)	EMISSION FACTORS FOR	ORE CRUSHING AND GRINDING
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Type Of Ore And Lead Content (wt %)		Particulate Emission Factor ^a	EMISSION FACTOR RATING	Lead Emission Factor ^b	EMISSION FACTOR RATING
Lead ^c (SCC 3-03-031-01)	5.1	6.0	В	0.30	В
Zinc ^d (SCC 3-03-031-02)	0.2	6.0	В	0.012	В
Copper ^e (SCC 3-03-031-03)	0.2	6.4	В	0.012	В
Lead-Zinc ^f (SCC 3-03-031-04)	2.0	6.0	В	0.12	В
Copper-Lead ^g (SCC 3-03-031-05)	2.0	6.4	В	0.12	В
Copper-Zinc ^h (SCC 3-03-031-06)	0.2	6.4	В	0.012	В
Copper-Lead-Zinc ⁱ (SCC 3-03-031-07)	2.0	6.4	В	0.12	В

^a Reference 2. Units are expressed as 1b of pollutant/ton ore processed. SCC = Source Classification Code.

^b Reference 2,3,5,7. ^c Refer to Section 12.6.

^d Characteristic of some mines in Colorado. ^e Characteristic of some mines in Alaska, Idaho, and New York.

^f Characteristic of Arizona mines.

^g Characteristic of some mines in Missouri, Idaho, Colorado, and Montana.

^h Characteristic of some mines in Missouri.

ⁱ Does not appear in ore characterization of the top 25 domestic lead producing mines.

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12.19 Electric Arc Welding

NOTE: Because of the many Source Classification Codes (SCCs) associated with electric arc welding, the text of this Section will give only the first 3 of the 4 SCC number fields. The last field of each applicable SCC will be found in Tables 12.19-1 and 12.19-2 below.

12.19.1 Process Description¹⁻²

Welding is the process by which 2 metal parts are joined by melting the parts at the points of contact and simultaneously forming a connection with molten metal from these same parts or from a consumable electrode. In welding, the most frequently used methods for generating heat employ either an electric arc or a gas-oxygen flame.

There are more than 80 different types of welding operations in commercial use. These operations include not only arc and oxyfuel welding, but also brazing, soldering, thermal cutting, and gauging operations. Figure 12.19-1 is a diagram of the major types of welding and related processes, showing their relationship to one another.

Of the various processes illustrated in Figure 12.19-1, electric arc welding is by far the most often found. It is also the process that has the greatest emission potential. Although the national distribution of arc welding processes by frequency of use is not now known, the percentage of electrodes consumed in 1991, by process type, was as follows:

Shielded metal arc welding (SMAW) - 45 percent Gas metal arc welding (GMAW) - 34 percent Flux cored arc welding (FCAW) - 17 percent Submerged arc welding (SAW) - 4 percent

12.19.1.1 Shielded Metal Arc Welding (SMAW)³ -

SMAW uses heat produced by an electric arc to melt a covered electrode and the welding joint at the base metal. During operation, the rod core both conducts electric current to produce the arc and provides filler metal for the joint. The core of the covered electrode consists of either a solid metal rod of drawn or cast material or a solid metal rod fabricated by encasing metal powders in a metallic sheath. The electrode covering provides stability to the arc and protects the molten metal by creating shielding gases by vaporization of the cover.

12.19.1.2 Gas Metal Arc Welding (GMAW)³ -

GMAW is a consumable electrode welding process that produces an arc between the pool of weld and a continuously supplied filler metal. An externally supplied gas is used to shield the arc.

12.19.1.3 Flux Cored Arc Welding (FCAW)³ -

FCAW is a consumable electrode welding process that uses the heat generated by an arc between the continuous filler metal electrode and the weld pool to bond the metals. Shielding gas is provided from flux contained in the tubular electrode. This flux cored electrode consists of a metal sheath surrounding a core of various powdered materials. During the welding process, the electrode core material produces a slag cover on the face of the weld bead. The welding pool can be protected from the atmosphere either by self-shielded vaporization of the flux core or with a separately supplied shielding gas.



Figure 12.19-1. Welding and allied processes. (Source Classification Codes in parentheses.)

12.19.1.4 Submerged Arc Welding (SAW)⁴ -

SAW produces an arc between a bare metal electrode and the work contained in a blanket of granular fusible flux. The flux submerges the arc and welding pool. The electrode generally serves as the filler material. The quality of the weld depends on the handling and care of the flux. The SAW process is limited to the downward and horizontal positions, but it has an extremely low fume formation rate.

12.19.2 Emissions And Controls⁴⁻⁸

12.19.2.1 Emissions -

Particulate matter and particulate-phase hazardous air pollutants are the major concerns in the welding processes. Only electric arc welding generates these pollutants in substantial quantities. The lower operating temperatures of the other welding processes cause fewer fumes to be released. Most of the particulate matter produced by welding is submicron in size and, as such, is considered to be all PM-10 (i. e., particles ≤ 10 micrometers in aerodynamic diameter).

The elemental composition of the fume varies with the electrode type and with the workpiece composition. Hazardous metals designated in the 1990 Clean Air Act Amendments that have been recorded in welding fume include manganese (Mg), nickel (Ni), chromium (Cr), cobalt (Co), and lead (Pb).

Gas phase pollutants are also generated during welding operations, but little information is available on these pollutants. Known gaseous pollutants (including "greenhouse" gases) include carbon dioxide (CO₂), carbon monoxide (CO), nitrogen oxides (NO_x), and ozone (O₃).

Table 12.19-1 presents PM-10 emission factors from SMAW, GMAW, FCAW, and SAW processes, for commonly used electrode types. Table 12.19-2 presents similar factors for hazardous metal emissions. Actual emissions will depend not only on the process and the electrode type, but also on the base metal material, voltage, current, arc length, shielding gas, travel speed, and welding electrode angle.

12.19.2.2 Controls -

The best way to control welding fumes is to choose the proper process and operating variables for the given task. Also, capture and collection systems may be used to contain the fume at the source and to remove the fume with a collector. Capture systems may be welding booths, hoods, torch fume extractors, flexible ducts, and portable ducts. Collection systems may be high efficiency filters, electrostatic precipitators, particulate scrubbers, and activated carbon filters.

Electrode Ty Welding Process (With Last 2 Digits		trode Type 2 Digits Of SCC)	Total Fume Emission Factor (g/kg [lb/10 ³ lb] Of Electrode Consumed) ^b	EMISSION FACTOR RATING		
SMAW ^c	14Mn-4Cr	(-04)	81.6	С		
(SCC 3-09-051)	E11018	(-08) ^h	16.4	C		
	E308	(-12) ^j	10.8	С		
	E310	(-16) ^k	15.1	С		
	E316	(-20) ^m	10.0	С		
	E410	(-24) ⁿ	13.2	D		
	E6010	(-28)	25.6	В		
	E6011	(-32)	38.4	С		
	E6012	(-36)	8.0	D		
	E6013	(-40)	19.7	В		
	E7018	(-44)	18.4	C		
	E7024	(-48)	9.2	C		
	E7028	(-52)	18.0	C		
	E8018	(-56) ^p	17.1	С		
	E9015	(-60) ^q	17.0	D		
	E9018	(-64) ^r	16.9	С		
	ECoCr	(-68) ⁸	27.9	С		
	ENi-Cl	(-72)	18.2	С		
	ENiCrMo	(-76) ^t	11.7	С		
	ENi-Cu	(-80) ^u	10.1	c		
			5.4	0		
GMAW ^{a,e}	E308L	(-12)*	5.4	C		
(SCC 3-09-052)	E70S	(-54)*	5.2	· A		
	ER1260	(-10)	20.5	D		
	ER5154	(-26)	24.1	D		
	ER316	(-20) ^x	3.2	С		
	ERNiCrMo	(-76) ^y	3.9	C		
	ERNiCu	(-80) ^z	2.0	С		

Table 12.19-1 (Metric And English Units). PM-10 EMISSION FACTORS FOR WELDING OPERATIONS^a

Table 12.19-1 (cont.).

Welding Process	Electrode Type (With Last 2 Digits Of SCC)		Total Fume Emission Factor (g/kg [lb/10 ³ lb] Of Electrode Consumed) ^b	EMISSION FACTOR RATING
FCAW ^{f,8} (SCC 3-09-053)	E110 E11018 E308LT E316LT E70T E71T	(-06) ^{aa} (-08) (-12) ^{bb} (-20) ^{cc} (-54) ^{dd} (-55) ^{ee}	20.8 57.0 9.1 8.5 15.1 12.2	D D C B B B
SAW ^g (SCC 3-09-054)	EM12K	(-10) ^{ff}	0.05	С

^a References 7-18. SMAW = shielded metal arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding; SAW = submerged arc welding. SCC = Source Classification Code.

^b Mass of pollutant emitted per unit mass of electrode consumed. All welding fume is considered to be PM-10 (particles $\leq 10 \,\mu$ m in aerodynamic diameter).

- ^c Current = 102 to 229 A; voltage = 21 to 34 V.
- ^d Current = 160 to 275 A; voltage = 20 to 32 V.
- ^c Current = 275 to 460 A; voltage = 19 to 32 V.
- ^f Current = 450 to 550 A; voltage = 31 to 32 V.
- ^g Type of shielding gas employed will influence emission factor.
- ^h Includes E11018-M
- ^j Includes E308-16 and E308L-15
- ^k Includes E310-16
- ^m Includes E316-15, E316-16, and E316L-16
- ⁿ Includes E410-16
- ^p Includes E8018C3
- ^q Includes E9015B3
- r Includes E9018B3 and E9018G
- ^s Includes ECoCr-A
- t Includes ENiCrMo-4
- ^u Includes ENi-Cu-2
- ^v Includes E308LSi
- ^w Includes E70S-3, E70S-5, and E70S-6
- ^x Includes ER316I-Si and ER316L-Si
- ^y Includes ENiCrMo-3 and ENi-CrMo-4
- ^z Includes ERNiCu-7
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- aa Includes E110TS-K3
- bb Includes E308LT-3
- ^{cc} Includes E316LT-3
- ^{dd} Includes E70T-1, E70T-2, E70T-4, E70T-5, E70T-7, and E70T-G
- ee Includes E71T-1 and E71T-11
- ^{ff} Includes EM12K1 and F72-EM12K2

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Table 12.19-2	HAZARDOUS A	IR POLLUTANT (HAP)	EMISSION FACTORS FOR	WELDING OPERATIONS ^a
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	Electroc	le Type	HAP Emission Factor (10 ⁻¹ g/kg [10 ⁻¹ /10 ³ lb] Of Electrode Consumed) ^b					ed) ^b	EMISSION
Welding Process	Of SCC)		Cr	Cr(VI)	Со	Mn	Ni	Pb	RATING
SMAW ^c	14Mn-4Cr	(-04)	13.9	ND	ND	232	17.1	ND	С
(SCC 3-09-051)	E11018	(-08) ^h	ND	ND	ND	13.8	ND	ND	С
	E308	(-12) ^j	3.93	3.59	0.01	2.52	0.43	ND	D
	E310	(-16) ^k	25.3	18.8	ND	22.0	1.96	0.24	С
	E316	(-20) ^m	5.22	3.32	ND	5.44	0.55	ND	D
	E410	(-24) ⁿ	ND	ND	ND .	6.85	0.14	ND	С
	E6010	(-28)	0.03	0.01	ND	9.91	0.04	ND	В
	E6011	(-32)	0.05	ND	0.01	9.98	0.05	ND	С
	E6012	(-36)	ND	ND	ND	ND	ND	ND	ND
	E6013	(-40)	0.04	ND	< 0.01	9.45	0.02	ND	В
	E7018	(-44)	0.06	ND	< 0.01	10.3	0.02	ND	С
	E7024	(-48)	0.01	ND	ND	6.29	ND	ND	С
	E7028	(-52)	0.13	ND	ND	8.4612	ND	1.62	С
	E8018	(-56) ^p	0.17	ND	ND	0.3	0.51	ND	С
	E9016	(-60)	ND	ND	ND	ND	ND	ND	ND
	E9018	(-6 4) ^q	2.12	ND	ND	7.83	0.13	ND	C
	ECoCr	(-68)	ND	ND	ND	ND	ND	ND	ND
	ENi-Cl	(-72)	ND	ND	ND	0.39	8.90	ND	C
	ENiCrMo	(-76) ^r	4.20	ND	ND	0.43	2.47	ND	С
	ENi-Cu-2	(-80) ^s	ND	ND	ND	2.12	4.23	ND	С
GMAW ^{d,e}	E308	(-12) ^t	5.24	ND	< 0.01	3.46	1.84	ND	с
(SCC 3-09-052)	E70S	(-54) ^u	0.01	ND	< 0.01	3.18	0.01	ND	Α
	ER1260	(-10)	0.04	ND	ND	ND	ND	ND	D
	ER5154	(-26)	0.10	ND	ND	0.34	ND	ND	D
	ER316	(-20) ^v	5.28	0.10	ND	2.45	2.26	ND	D
	ERNiCrMo	(-76) ^w	3.53	ND	ND	0.70	12.5	ND	В
	ERNiCu	(-80) ^x	< 0.01	ND	ND	0.22	4.51	ND	С

Table 12.19-2 (cont.).

	Electroc (With Las	Electrode Type (With Last 2 Digita HAP Emission Factor (10 ⁻¹ g/kg [10 ⁻¹ lb/10 ³ lb] Of Electrode Consumed) ^b						EMISSION	
Welding Process	Of S	Of SCC)		Cr(VI)	Со	Mn	Ni	Pb	RATING
FCAW ^{f,g}	E110	(-06) ^y	0.02	ND	ND	20.2	1.12	ND	D
(SCC 3-09-053)	E11018	(-08) ^z	9.69	ND	ND	7.04	1.02	ND	C
	E308	(-12)	ND	ND	ND	ND	ND	ND	ND
	E316	(-20) ^{aa}	9.70	1.40	ND	5.90	0.93	ND	B
	E70T	(-54) ^{bb}	0.04	ND	ND	8.91	0.05	ND	B
	E71T	(-55) ^{cc}	0.02	ND	< 0.01	6.62	0.04	ND	B
SAW ^h (SCC 3-09-054)	EM12K	(-10)	ND	ND	ND	ND	ND	ND	ND

^a References 7-18. SMAW = shielded metal arc welding; GMAW = gas metal arc welding; FCAW = flux cored arc welding;

SAW = submerged arc welding. SCC = Source Classification Code. ND = no data.

^b Mass of pollutant emitted per unit mass of electrode consumed. Cr = chromium. Cr(VI) = chromium + 6 valence state. Co = cobalt. Mn = manganese. Ni = nickel. Pb = lead. All HAP emissions are in the PM-10 size range (particles $\leq 10 \ \mu$ m in aerodynamic diameter).

^c Current = 102 to 225 A; voltage = 21 to 34 V.

^d Current = 275 to 460 A; voltage = 19 to 32 V.

^e Type of shielding gas employed will influence emission factors.

^f Current = 160 to 275 A; voltage = 22 to 34 V.

- ^g Current = 450 to 550 A; voltage = 31 to 32 V.
- h Includes E11018-M
- ^j Includes E308-16 and E308L-15
- ^k Includes E310-15
- ^m Includes E316-15, E316-16, and E316L-16
- ⁿ Includes E410-16
- ^p Includes 8018C3
- ^q Includes 9018B3
- r Includes ENiCrMo-3 and ENiCrMo-4
- ^s Includes ENi-Cu-2
- ^t Includes E308LSi
- ^u Includes E70S-3, E70S-5, and E70S-6
- V Includes ER316I-Si
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- ^w Includes ERNiCrMo-3 and ERNiCrMo-4
- x Includes ERNiCu-7
- ^y Includes E110TS-K3
- ^z Includes E11018-M
- ^{aa} Includes E316LT-3
- ^{bb} Includes E70T-1, E70T-2, E70T-4, E70T-5, E70T-7, and E70T-G
- cc Includes E71T-1 and E71T-11

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12.20 Electroplating

This section addresses the electroplating industry. However, emphasis is placed on chromium electroplating and chromic acid anodizing because the majority of emissions data and other information available were for this area of the electroplating industry. Detailed information on the process operations, emissions, and controls associated with other types of electroplating will be added to this section as it becomes available. The six-digit Source Classification Code (SCC) for electroplating is 3-09-010.

12.20.1 Process Description¹⁻⁴

Electroplating is the process of applying a metallic coating to an article by passing an electric current through an electrolyte in contact with the article, thereby forming a surface having properties or dimensions different from those of the article. Essentially any electrically conductive surface can be electroplated. Special techniques, such as coating with metallic-loaded paints or silver-reduced spray, can be used to make nonconductive surfaces, such as plastic, electrically conductive for electroplating. The metals and alloy substrates electroplated on a commercial scale are cadmium, chromium, cobalt, copper, gold, indium, iron, lead, nickel, platinum group metals, silver, tin, zinc, brass, bronze, many gold alloys, lead-tin, nickel-iron, nickel-cobalt, nickel-phosphorus, tin-nickel, tin-zinc, zinc-nickel, zinc-cobalt, and zinc-iron. Electroplated materials are generally used for a specific property or function, although there may be some overlap, e. g., a material may be electroplated for decorative use as well as for corrosion resistance.

The essential components of an electroplating process are an electrode to be plated (the cathode or substrate), a second electrode to complete the circuit (the anode), an electrolyte containing the metal ions to be deposited, and a direct current power source. The electrodes are immersed in the electrolyte with the anode connected to the positive leg of the power supply and the cathode to the negative leg. As the current is increased from zero, a point is reached where metal plating begins to occur on the cathode. The plating tank is either made of or lined with totally inert materials to protect the tank. Anodes can be either soluble or insoluble, with most electroplating baths using one or the other type. The majority of power supplies are solid-state silicon rectifiers, which may have a variety of modifications, such as stepless controls, constant current, and constant voltage. Plate thickness is dependent on the cathode efficiency of a particular plating solution, the current density, and the amount of plating time. The following section describes the electroplating process. Following the description of chromium plating, information is provided on process parameters for other types of electroplating.

12.20.1.1 Chromium Electroplating -

Chromium plating and anodizing operations include hard chromium electroplating of metals, decorative chromium electroplating of metals, decorative chromium electroplating of plastics, chromic acid anodizing, and trivalent chromium plating. Each of these categories of the chromium electroplating industry is described below.

Hard Chromium Electroplating -

In hard plating, a relatively thick layer of chromium is deposited directly on the base metal (usually steel) to provide a surface with wear resistance, a low coefficient of friction, hardness, and corrosion resistance, or to build up surfaces that have been eroded by use. Hard plating is used for items such as hydraulic cylinders and rods, industrial rolls, zinc die castings, plastic molds, engine components, and marine hardware.

Figure 12.20-1 presents a process flow diagram for hard chromium electroplating. The process consists of pretreatment, alkaline cleaning, acid dipping, chromic acid anodizing, and chromium electroplating. The pretreatment step may include polishing, grinding, and degreasing. Degreasing consists of either dipping the part in organic solvents, such as trichloroethylene or perchloroethylene, or using the vapors from organic solvents to remove surface grease. Alkaline cleaning is used to dislodge surface soil with inorganic cleaning solutions, such as sodium carbonate, sodium phosphate, or sodium hydroxide. Acid dipping, which is optional, is used to remove tarnish or oxide films formed in the alkaline cleaning step and to neutralize the alkaline film. Acid dip solutions typically contain 10 to 30 percent hydrochloric or sulfuric acid. Chromic acid anodic treatment, which also is optional, cleans the metal surface and enhances the adhesion of chromium in the electroplating step. The final step in the process is the electroplating operation itself.

The plating tanks typically are equipped with some type of heat exchanger. Mechanical agitators or compressed air supplied through pipes on the tank bottom provide uniformity of bath temperature and composition. Chromium electroplating requires constant control of the plating bath temperature, current density, plating time, and bath composition.

Hexavalent chromium plating baths are the most widely used baths to deposit chromium on metal. Hexavalent chromium baths are composed of chromic acid, sulfuric acid, and water. The chromic acid is the source of the hexavalent chromium that reacts and deposits on the metal and is emitted to the atmosphere. The sulfuric acid in the bath catalyzes the chromium deposition reactions.

The evolution of hydrogen gas from chemical reactions at the cathode consumes 80 to 90 percent of the power supplied to the plating bath, leaving the remaining 10 to 20 percent for the deposition reaction. When the hydrogen gas evolves, it causes misting at the surface of the plating bath, which results in the loss of chromic acid to the atmosphere.

Decorative Chromium Electroplating -

Decorative chromium electroplating is applied to metals and plastics. In decorative plating of metals, the base material generally is plated with layers of copper and nickel followed by a relatively thin layer of chromium to provide a bright surface with wear and tarnish resistance. Decorative plating is used for items such as automotive trim, metal furniture, bicycles, hand tools, and plumbing fixtures.

Figure 12.20-2 presents a process flow diagram for decorative chromium electroplating. The process consists of pretreatment, alkaline cleaning, and acid dipping, which were described previously, followed by strike plating of copper, copper electroplating, nickel electroplating, and chromium electroplating. The copper strike plating step consists of applying a thin layer of copper in a copper cyanide solution to enhance the conductive properties of the base metal. Following the copper strike plate, the substrate is acid dipped again, and then electroplated with an undercoat of copper to improve corrosion resistance and cover defects. Either a copper cyanide or acid copper solution is used in this step. The substrate then is plated with nickel in two layers (semibright nickel and bright nickel) to further improve corrosion resistance and activate the surface metal for chromium electroplating.



Figure 12.20-1. Flow diagram for a typical hard chromium plating process.³ (Source Classification Codes in parentheses.)

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Figure 12.20-2. Flow diagram for decorative chromium plating on a metal substrate.³ (Source Classification Codes in parentheses.)

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Semibright and bright nickel plating both use Watts plating baths. The final step in the process is the electroplating operation itself.

Decorative electroplating baths operate on the same principle as that of the hard chromium plating process. However, decorative chromium plating requires shorter plating times and operates at lower current densities than does hard chromium plating. Some decorative chromium plating operations use fluoride catalysts instead of sulfuric acid because fluoride catalysts, such as fluosilicate or fluoborate, have been found to produce higher bath efficiencies.

Most plastics that are electroplated with chromium are formed from acrylonitrile butadiene styrene (ABS). The process for chromium electroplating of ABS plastics consists of the following steps: chromic acid/sulfuric acid etch; dilute hydrochloric acid dip; colloidal palladium activation; dilute hydrochloric acid dip; electroless nickel plating or copper plating; and chromium electroplating cycle. After each process step, the plastic is rinsed with water to prevent carry-over of solution from one bath to another. The electroplating of plastics follows the same cycle as that described for decorative chromium electroplating.

Chromic Acid Anodizing -

Chromic acid anodizing is used primarily on aircraft parts and architectural structures that are subject to high stress and corrosion. Chromic acid anodizing is used to provide an oxide layer on aluminum for corrosion protection, electrical insulation, ease of coloring, and improved dielectric strength. Figure 12.20-3 presents a flow diagram for a typical chromic acid anodizing process.

There are four primary differences between the equipment used for chromium electroplating and that used for chromic acid anodizing: chromic acid anodizing requires the rectifier to be fitted with a rheostat or other control mechanism to permit starting at about 5 V; the tank is the cathode in the electrical circuit; the aluminum substrate acts as the anode; and sidewall shields typically are used instead of a liner in the tank to minimize short circuits and to decrease the effective cathode area. Types of shield materials used are herculite glass, wire safety glass, neoprene, and vinyl chloride polymers.

Before anodizing, the aluminum must be pretreated by means of the following steps: alkaline soak, desmutting, etching, and vapor degreasing. The pretreatment steps used for a particular aluminum substrate depend upon the amount of smut and the composition of the aluminum. The aluminum substrate is rinsed between pretreatment steps to remove cleaners.

During anodizing, the voltage is applied step-wise (5 V per minute) from 0 to 40 V and maintained at 40 V for the remainder of the anodizing time. A low starting voltage (i. e., 5 V) minimizes current surge that may cause "burning" at contact points between the rack and the aluminum part. The process is effective over a wide range of voltages, temperatures, and anodizing times. All other factors being equal, high voltages tend to produce bright transparent films, and lower voltages tend to produce opaque films. Raising the bath temperature increases current density to produce thicker films in a given time period. Temperatures up to 49° C (120° F) typically are used to produce films that are to be colored by dyeing. The amount of current varies depending on the size of the aluminum parts; however, the current density typically ranges from 1,550 to 7,750 A/m² (144 to 720 A/ft²).

The postanodizing steps include sealing and air drying. Sealing causes hydration of the aluminum oxide and fills the pores in the aluminum surface. As a result, the elasticity of the oxide film increases, but the hardness and wear resistance decrease. Sealing is performed by immersing

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Figure 12.20-3. Flow diagram for a typical chromic acid anodizing process.³ (Source Classification Codes in parentheses.)

aluminum in a water bath at 88° to 99°C (190° to 210°F) for a minimum of 15 minutes. Chromic acid or other chromates may be added to the solution to help improve corrosion resistance. The aluminum is allowed to air dry after it is sealed.

Trivalent Chromium Plating -

Trivalent chromium electroplating baths have been developed primarily to replace decorative hexavalent chromium plating baths. Development of a trivalent bath has proven to be difficult because trivalent chromium solvates in water to form complex stable ions that do not readily release chromium. Currently, there are two types of trivalent chromium processes on the market: single-cell and double-cell. The major differences in the two processes are that the double-cell process solution contains minimal-to-no chlorides, whereas the single-cell process solution contains a high concentration of chlorides. In addition, the double-cell process utilizes lead anodes that are placed in anode boxes that contain a dilute sulfuric acid solution and are lined with a permeable membrane, whereas the single-cell process are not available because the trivalent chromium baths currently on the market are proprietary.

The advantages of the trivalent chromium processes over the hexavalent chromium process are fewer environmental concerns due to the lower toxicity of trivalent chromium, higher productivity, and lower operating costs. In the trivalent chromium process, hexavalent chromium is a plating bath contaminant. Therefore, the bath does not contain any appreciable amount of hexavalent chromium. The total chromium concentration of trivalent chromium solutions is approximately one-fifth that of hexavalent chromium solutions. As a result of the chemistry of the trivalent chromium electrolyte, misting does not occur during plating as it does during hexavalent chromium plating. Use of trivalent chromium also reduces waste disposal problems and costs.

The disadvantages of the trivalent chromium process are that the process is more sensitive to contamination than the hexavalent chromium process, and the trivalent chromium process cannot plate the full range of plate thicknesses that the hexavalent chromium process can. Because it is sensitive to contamination, the trivalent chromium process requires more thorough rinsing and tighter laboratory control than does the hexavalent chromium process. Trivalent chromium baths can plate thicknesses ranging up to 0.13 to 25 μ m (0.005 to 1.0 mils) and, therefore, cannot be used for most hard chromium plating applications. The hexavalent chromium process can plate thicknesses up to 762 μ m (30 mils).

12.20.1.2 Electroplating-Other Metals -

Brass Electroplating -

Brass, which is an alloy of copper and uzinc, is the most widely used alloy electroplate. Brass plating primarily is used for decorative applications, but it is also used for engineering applications such as for plating steel wire cord for steel-belted radial tires. Although all of the alloys of copper and zinc can be plated, the brass alloy most often used includes 70 to 80 percent copper, with the balance zinc. Typical brass plating baths include 34 g/L (4.2 oz/gal) of copper cyanide and 10 g/L (1.3 oz/gal) of zinc cyanide. Other bath constituents include sodium cyanide, soda ash, and ammonia.

Cadmium Electroplating -

Cadmium plating generally is performed in alkaline cyanide baths that are prepared by dissolving cadmium oxide in a sodium cyanide solution. However, because of the hazards associated with cyanide use, noncyanide cadmium plating solutions are being used more widely. The primary noncyanide plating solutions are neutral sulfate, acid fluoborate, and acid sulfate. The cadmium concentration in plating baths ranges from 3.7 to 94 g/L (0.5 to 12.6 oz/gal) depending on the type of solution. Current densities range from 22 to 970 A/m² (2 to 90 A/ft²).

Copper Electroplating -

Copper cyanide plating is widely used in many plating operations as a strike. However, its use for thick deposits is decreasing. For copper cyanide plating, cuprous cyanide must be complexed with either potassium or sodium to form soluble copper compounds in aqueous solutions. Copper cyanide plating baths typically contain 30 g/L (4.0 oz/gal) of copper cyanide and either 59 g/L (7.8 oz/gal) of potassium cyanide or 48 g/L (6.4 oz/gal) of sodium cyanide. Current densities range from 54 to 430 A/m^2 (5 to 40 A/ft^2). Cathode efficiencies range from 30 to 60 percent.

Other types of baths used in copper plating include copper pyrophosphate and copper sulfate baths. Copper pyrophosphate plating, which is used for plating on plastics and printed circuits, requires more control and maintenance of the plating baths than copper cyanide plating does. However, copper pyrophosphate solutions are relatively nontoxic. Copper pyrophosphate plating baths typically contain 53 to 84 g/L (7.0 to 11.2 oz/gal) of copper pyrophosphate and 200 to 350 g/L (27 to 47 oz/gal) of potassium pyrophosphate. Current densities range from 110 to 860 A/m² (10 to 80 A/ft^2).

Copper sulfate baths, which are more economical to prepare and operate than copper pyrophosphate baths, are used for plating printed circuits, electronics, rotogravure, and plastics, and for electroforming and decorative uses. In this type of bath copper and sulfate and sulfuric acid form the ionized species in solution. Copper sulphate plating baths typically contain 195 to 248 g/L (26 to 33 oz/gal) of copper sulphate and 11 to 75 g/L (1.5 to 10 oz/gal) of sulfuric acid. Current densities range from 215 to 1,080 A/m² (20 to 100 A/ft²).

Gold Electroplating -

Gold and gold alloy plating are used in a wide variety of applications. Gold plating solutions can be classified in five general groups: alkaline gold cyanide, for gold and gold alloy plating; neutral cyanide gold, for high purity gold plating; acid gold cyanide, for bright hard gold and gold alloy plating; noncyanide (generally sulfite), for gold and gold plating; and miscellaneous. Alkaline gold cyanide plating baths contain 8 to 20 g/L (1.1 to 2.7 oz/gal) of potassium gold cyanide and 15 to 100 g/L (2.0 to 13.4 oz/gal) of potassium cyanide. Current densities range from 11 to 86 A/m² (1.0 to 8 A/ft²) and cathode efficiencies range from 90 to 100 percent.

Neutral gold cyanide plating baths contain 8 to 30 g/L (1.1 to 4.0 oz/gal) of potassium gold cyanide. Current densities range from 11 to 4,300 A/m² (1.0 to 400 A/ft²), and cathode efficiencies range from 90 to 98 percent.

Acid gold cyanide plating baths contain 8 to 16 g/L (1.1 to 2.1 oz/gal) of potassium gold cyanide. Current densities range from 11 to $4,300 \text{ A/m}^2$ (1.0 to 400 A/ft²), and cathode efficiencies range from 30 to 40 percent.

Indium Electroplating -

In general, indium is electroplated using three types of plating baths: cyanide, sulfamate, and fluoborate. Indium is the only trivalent metal that can be electrodeposited readily from a cyanide solution. Cyanide baths are used in applications that require very high throwing power and adhesion. Indium cyanide plating baths typically contain 33 g/L (4.0 oz/gal) of indium metal and 96 g/L (12.8 oz/gal) of total cyanide. Current densities range from 162 to 216 A/m² (15 to 20 A/ft²), and cathode efficiencies range from 50 to 75 percent.

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Indium sulfamate baths are very stable, relatively easy to control, and characterized by a high cathode efficiency that remains relatively high (90 percent). The plating baths typically contain 105 g/L (14 oz/gal) of indium sulfamate and 26 g/L (3.5 oz/gal) of sulfamic acid. Current densities range from 108 to 1,080 A/m² (10 to 100 A/ft²).

Indium fluoborate plating baths typically contain 236 g/L (31.5 oz/gal) of indium fluoborate and 22 to 30 g/L (2.9 to 4.0 oz/gal) of boric acid. Current densities range from 540 to 1,080 A/m² (50 to 100 A/ft²), and cathode efficiencies range from 40 to 75 percent.

Nickel Electroplating -

Nickel plating is used for decorative, engineering, and electroforming purposes. Decorative nickel plating differs from other types of nickel plating in that the solutions contain organic agents, such as benzene disulfonic acids, benzene trisulfonic acid, naphthalene trisulfonic acid, benzene sulfonamide, formaldehyde, coumarin, ethylene cyanohydrin, and butynediol. Nickel plating for engineering applications uses solutions that deposit pure nickel. In nickel plating baths, the total nickel content ranges from 60 to 84 g/L (8 to 11.2 oz/gal), and boric acid concentrations range from 30 to 37.5 g/L (4 to 5 oz/gal). Current densities range from 540 to 600 A/m² (50 to 60 A/ft²), and cathode efficiencies range from 93 to 97 percent.

Palladium and Palladium-Nickel Electroplating -

Palladium plating solutions are categorized as ammoniacal, chelated, or acid. Ammoniacal palladium plating baths contain 10 to 15 g/L (1.3 to 2.0 oz/gal) of palladium ammonium nitrate or palladium ammonium chloride, and current densities range from 1 to 25 A/m² (0.093 to 2.3 A/ft²). Palladium acid plating baths contain 50 g/L (6.7 oz/gal) of palladium chloride, and current densities range from 1 to 10 A/m² (0.093 to 0.93 A/ft²).

Palladium alloys readily with other metals, the most important of which is nickel. Palladium nickel electroplating baths contain 3 g/L (6.7 oz/gal) of palladium metal and 3 g/L (6.7 oz/gal) of nickel metal.

Platinum Electroplating -

Solutions used for platinum plating are similar to those used for palladium plating. Plating baths contain 5.0 to 20 g/L (0.68 oz/gal) of either dinitroplatinite sulfate or chloroplatinic acid, and current densities range from 1 to 20 A/m² (0.093 to 1.86 A/ft²).

Rhodium Electroplating -

Rhodium plating traditionally has been used as decorative plating in jewelry and silverware. However, the use of rhodium plating for electronics and other industrial applications has been increasing in recent years. For decorative plating, rhodium baths contain 1.3 to 2.0 g/L (0.17 to 0.27 oz/gal) of rhodium phosphate or rhodium sulfate concentrate and 25 to 80 ml/L (3.0 to 11 oz/gal) of phosphoric or sulfuric acid. Current densities typically range from 20 to 100 A/m² (1.86 to 9.3 A-ft²). For industrial and electronic applications, rhodium plating baths contain approximately 5.0 g/L (0.67 oz/gal) of rhodium metal as sulfate concentrate and 25 to 50 ml/L (3.0 to 7.0 oz/gal) of sulfuric acid. Current densities typically range from 10 to 30 A/m² (0.93 to 2.79 A-ft²), and cathode efficiency ranges from 70 to 90 percent with agitation or 50 to 60 percent without agitation.

Ruthenium Electroplating -

Electroplated ruthenium is a very good electrical conductor and produces a very hard deposit. Typical plating baths contain approximately 5.3 g/L (0.71 oz/gal) of ruthenium as sulfamate or nitrosyl

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sulfamate and 8.0 g/L (1.1 oz/gal) of sulfamic acid. Current densities typically range from 108 to 320 A/m^2 (10 to 30 A-ft²), and cathode efficiency is typically about 20 percent.

Silver Electroplating -

Silver plating traditionally has been performed using a cyanide-based plating solution. Although some noncyanide solutions have been developed, due to various shortcomings, cyanide solutions still are commonly used. Typical plating baths contain 5.0 to 40 g/L (0.67 to 5.3 oz/gal) of silver as potassium silver cyanide and 12 to 120 g/L (1.6 to 16 oz/gal) of potassium cyanide. Current densities typically range from 11 to 430 A/m² (1 to 40 A-ft²).

Tin-Lead, Lead, and Tin Electroplating -

Fluoborate and fluoboric acid can be used to plate all percentages of tin and lead. Alloys of tin and lead are most commonly used for plating in the proportions of 60 percent tin and 40 percent lead. Tin-lead plating baths typically contain 52 to 60 g/L (7.0 to 8.0 oz/gal) of stannous tin, 23 to 30 g/L (3.0 to 4.0 oz/gal) of lead, 98 to 150 g/L (13 to 20 oz/gal) of fluoboric acid, and 23 to 38 g/L (3.0 to 5.0 oz/gal) of boric acid. Current densities typically range from 270 to 380 A/m² (25 to 35 A-ft²).

Lead fluoborate plating baths typically contain 340 to 410 g/L (45 to 55 oz/gal) of lead fluoborate, 195 to 240 g/L (26 to 32 oz/gal) of lead, 15 to 30 g/L (2.0 to 4.0 oz/gal) of fluoboric acid, and 23 to 38 g/L (3.0 to 5.0 oz/gal) of boric acid. Current densities typically range from 215 to 750 A/m^2 (20 to 70 A-ft²).

Tin plating generally is performed using one of three types of plating solutions (stannous fluoborate, stannous sulfate, or sodium or potassium stannate) or by the halogen tin process. Stannous fluoborate plating baths include 75 to 110 g/L (10 to 15 oz/gal) of stannous fluoborate, 30 to 45 g/L (4.0 to 6.0 oz/gal) of tin, 190 to 260 g/L (25 to 35 oz/gal) of fluoboric acid, and 23 to 38 g/L (3.0 to 5.0 oz/gal) of boric acid. Current densities typically range from 215 to 270 A/m² (20 to 25 A-ft²), and cathode efficiencies are greater than 95 percent.

Stannous sulfate plating baths include 15 to 45 g/L (2.0 to 6.0 oz/gal) of stannous sulfate, 7.5 to 22.5 g/L (1.0 to 3.0 oz/gal) of stannous tin, and 135 to 210 g/L (18 to 28 oz/gal) of sulfuric acid. Current densities typically range from 10 to 270 A/m² (1 to 25 A-ft²), and cathode efficiencies are greater than 95 percent.

Sodium/potassium stannate plating baths include 90 to 180 g/L (12 to 24 oz/gal) of sodium stannate or 100 to 200 g/L (13 to 27 oz/gal) of potassium stannate and 40 to 80 g/L (5.3 to 11 oz/gal) of tin metal. Current densities typically range from 10 to 1,080 A/m² (1 to 100 A-ft²).

Tin-Nickel Electroplating -

Tin-nickel alloy plating is used in light engineering and electronic applications and is used as an alternative to decorative chromium plating. Tin-nickel fluoride plating baths contain 49 g/L (6.5 oz/gal) of stannous chloride anhydrous, 300 g/L (40 oz/gal) of nickel chloride, and 56 g/L (7.5 oz/gal) of ammonium bifluoride. Current densities are typically about 270 A/m² (25 A-ft²).

Tin-nickel pyrophosphate plating baths contain 28 g/L (3.2 oz/gal) of stannous chloride, 31 g/L (4.2 oz/gal) of nickel chloride, and 190 g/L (26 oz/gal) of potassium pyrophosphate. Current densities range from 52 to 150 A/m² (4.8 to 14 A-ft²).

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Zinc Electroplating -

The most widely used zinc plating solutions are categorized as acid chloride, alkaline noncyanide, and cyanide. The most widely used zinc alloys for electroplating are zinc-nickel, zinc-cobalt, and zinc-iron. Zinc plating baths contain 15 to 38 g/L (2.0 to 5.0 oz/gal) of acid chloride zinc, 6.0 to 23 g/L (0.80 to 3.0 oz/gal) of alkaline noncyanide zinc, or 7.5 to 34 g/L (1.0 to 4.5 oz/gal) of cyanide zinc.

Acid zinc-nickel plating baths contain 120 to 130 g/L (16 to 17 oz/gal) of zinc chloride and 110 to 130 g/L (15 to 17 oz/gal) of nickel chloride. Alkaline zinc-nickel plating baths contain 8.0 g/L (1.1 oz/gal) of zinc metal and 1.6 g/L (0.21 oz/gal) of nickel metal. Current densities range from 5.0 to 40 A/m² (0.46 to 3.7 A-ft²) and 20 to 100 A/m² (1.9 to 9.3 A/ft²) for acid and alkaline baths, respectively.

Acid zinc-cobalt plating baths contain 30 g/L (4.0 oz/gal) of zinc metal and 1.9 to 3.8 g/L (0.25 to 0.51 oz/gal) of cobalt metal. Alkaline zinc-cobalt plating baths contain 6.0 to 9.0 g/L (0.80 to 1.2 oz/gal) of zinc metal and 0.030 to 0.050 g/L (0.0040 to 0.0067 oz/gal) of cobalt metal. Current densities range from 1.0 to 500 A/m² (0.093 to 46 A-ft²) and 20 to 40 A/m² (1.9 to 3.7 A/ft²) for acid and alkaline baths, respectively.

Acid zinc-iron plating baths contain 200 to 300 g/L (27 to 40 oz/gal) of ferric sulfate and 200 to 300 g/L (27 to 40 oz/gal) of zinc sulfate. Alkaline zinc-iron plating baths contain 20 to 25 g/L (2.7 to 3.3 oz/gal) of zinc metal and 0.25 to 0.50 g/L (0.033 to 0.067 oz/gal) of iron metal. Current densities range from 15 to 30 A/m² (1.4 to 2.8 A-ft²).

12.20.2 Emissions and Controls^{2-3,43-44}

Plating operations generate mists due to the evolution of hydrogen and oxygen gas. The gases are formed in the process tanks on the surface of the submerged part or on anodes or cathodes. As these gas bubbles rise to the surface, they escape into the air and may carry considerable liquid with them in the form of a fine mist. The rate of gassing is a function of the chemical or electrochemical activity in the tank and increases with the amount of work in the tank, the strength and temperature of the solution, and the current densities in the plating tanks. Air sparging also can result in emissions from the bursting of air bubbles at the surface of the plating tank liquid.

Emissions are also generated from surface preparation steps, such as alkaline cleaning, acid dipping, and vapor degreasing. These emissions are in the form of alkaline and acid mists and solvent vapors. The extent of acid misting from the plating processes depends mainly on the efficiency of the plating bath and the degree of air sparging or mechanical agitation. For many metals, plating baths have high cathode efficiencies so that the generation of mist is minimal. However, the cathode efficiency of chromium plating baths is very low (10 to 20 percent), and a substantial quantity of chromic acid mist is generated. The following paragraphs describe the methods used to control emissions from chromium electroplating. These methods generally apply to other types of plating operations as well.

Emissions of chromic acid mist from the electrodeposition of chromium from chromic acid plating baths occur because of the inefficiency of the hexavalent chromium plating process. Only about 10 to 20 percent of the current applied actually is used to deposit chromium on the item plated; the remaining 80 to 90 percent of the current applied is consumed by the evolution of hydrogen gas at the cathode with the resultant liberation of gas bubbles. Additional bubbles are formed at the anode

due to the evolution of oxygen. As the bubbles burst at the surface of the plating solution, a fine mist of chromic acid droplets is formed.

The principal techniques used to control emissions of chromic acid mist from decorative and hard chromium plating and chromic acid anodizing operations include add-on control devices and chemical fume suppressants. The control devices most frequently used are mist eliminators and wet scrubbers that are operated at relatively low pressure drops. Because of the corrosive properties of chromic acid, control devices typically are made of polyvinyl chloride (PVC) or fiberglass.

Chemical fume suppressants are added to decorative chromium plating and chromic acid anodizing baths to reduce chromic acid mist. Although chemical agents alone are effective control techniques, many plants use them in conjunction with an add-on control device.

Chevron-blade and mesh-pad mist eliminators are the types of mist eliminators most frequently used to control chromic acid mist. The most important mechanism by which mist eliminators remove chromic acid droplets from gas streams is the inertial impaction of droplets onto a stationary set of blades or a mesh pad. Mist eliminators typically are operated as dry units that are periodically washed down with water to clean the impaction media.

The wet scrubbers typically used to control emissions of chromic acid mist from chromium plating, and chromic acid anodizing operations are single and double packed-bed scrubbers. Other scrubber types used less frequently include fan-separator packed-bed and centrifugal-flow scrubbers. Scrubbers remove chromic acid droplets from the gas stream by humidifying the gas stream to increase the mass of the droplet particles, which are then removed by impingement on a packed bed. Once-through water or recirculated water typically is used as the scrubbing liquid because chromic acid is highly soluble in water.

Chemical fume suppressants are surface-active compounds that are added directly to chromium plating and chromic acid anodizing baths to reduce or control misting. Fume suppressants are classified as temporary or as permanent. Temporary fume suppressants are depleted mainly by the decomposition of the fume suppressant and dragout of the plating solution, and permanent fume suppressant are depleted mainly by dragout of the plating solution. Fume suppressants include wetting agents that reduce misting by lowering the surface tension of the plating or anodizing bath, foam blankets that entrap chromic acid mist at the surface of the plating solution, or combinations of both a wetting agent and foam blanket. Polypropylene balls, which float on the surface of the plating baths, also are used as a fume suppressant in chromium plating tanks.

National emission standards to regulate chromium emissions from new and existing hard and decorative chromium electroplating and chromium anodizing tanks at major and area sources were promulgated on January 25, 1995 (60 FR 4948). The regulation requires limits on the concentration of chromium emitted to the atmosphere (or alternative limits on the surface tension of the bath for decorative chromium electroplating and anodizing tanks) and specifies work practice standards, initial performance testing, ongoing compliance monitoring, recordkeeping, and reporting requirements.

Table 12.20-1 presents the emission factors for chromium electroplating. The emission factors are based on total energy input and are presented in units of grains per ampere-hour (grains/A-hr). For controlled emissions from chromium electroplating operations, each of the add-on control devices used in the industry generally achieves a narrow range of outlet concentrations of chromium, regardless of the level of energy input. For this reason, total energy input may not be an appropriate basis for establishing emission factors for this industry. Therefore, the factors for chromium electroplating tanks

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in Table 12.20-1 are presented both as concentrations and in units of total energy input. Emission rates for controlled emissions should be estimated using the concentration factors and typical exhaust flow rates for the particular type of exhaust system in question. The factors for controlled emissions based on total energy input should only be used in the absence of site-specific information.

Table 12.20-2 presents emission factors for chromic acid anodizing. The emission factors are presented in units of grains per hour per square foot (grains/hr-ft²) of tank surface area. Table 12.20-3 presents particle size distributions for hard chromium electroplating. Table 12.20-4 presents emission factors for the plating of metals other than chromium.

Emissions from plating operations other than chromium electroplating can be estimated using the emission factors and operating parameters for chromium electroplating. Equation 1 below provides an estimate of uncontrolled emissions from nonchromium plating tanks.

$$EF_{m} = 3.3 \times 10^{-7} \times (EE_{m}/e_{m}) \times C_{m} \times D_{m}$$
 (1)

where:

 EF_m = emission factor for metal "m", grains/dscf; EE_{m}^{m} = electrochemical equivalent for metal "m", A-hr/mil-ft²; $e_m =$ cathode efficiency for metal "m", percent; C_{m} = bath concentration for metal "m", oz/gal; and D_{m}^{--} = current density for metal "m", A/ft².

Equation 2 below provides an estimate of controlled emissions from nonchromium plating tanks.

$$EF_{m} = 0.028 \text{ x } EF_{Cr} \text{ x } C_{m}$$

$$\tag{2}$$

where EF_m and C_m are as defined above, and EF_{Cr} = emission factor for controlled hard chromium electroplating emissions, grains/dscf.

Equations 1 and 2 estimate emissions from the formation of gas as a result of the electrical energy applied to the plating tank; the equations do not account for additional emissions that result from air sparging or mechanical agitation of the tank solution. To estimate uncontrolled emissions due to air sparging, the following equation should be used:

$$E_{1} = 100 \ k_{1}R_{b}^{2} \left[\frac{(1 - 2a + 9a^{2})^{0.5} + (a - 1)}{(1 + 3a) - (1 - 2a + 9a^{2})^{0.5}} \right]^{5.5}$$

$$a = \frac{6.45 \ R_{b}^{2}}{k_{2}}, \ k_{1} = \frac{56.7 \ \sigma}{c_{s}^{2}}, \ k_{2} = \frac{1.79 \ x \ 10^{5} \ \sigma}{(\rho_{1} - \rho_{g}) \ g}$$
(3)
where:

$$\begin{split} E_1 &= \text{ emission factor, grains/bubble;} \\ R_b &= \text{ average bubble radius, in.;} \\ \sigma &= \text{ surface tension of bath, pounds force per foot (lb_f/ft);} \\ c_s &= \text{ speed of sound, ft/sec;} \\ \rho_1 &= \text{ density of liquid, lb/ft}^3; \\ \rho_g &= \text{ density of gas (air), lb/ft}^3; \text{ and} \\ g &= \text{ acceleration due to gravity, ft/sec}^2. \end{split}$$

Substituting typical values for constants c_s (1,140 ft/sec), g (32.2 ft/sec²), and assuming values for ρ_l of 62.4 lb/ft³ and for ρ_p of 0.0763 lb/ft³, Equation 3 can be reduced to the following equation:

$$E_{2} = \frac{1.9 \sigma}{R_{b}} \left[\frac{(1 - 2a + 9a^{2})^{0.5} + (a - 1)}{(1 + 3a) - (1 - 2a + 9a^{2})^{0.5}} \right]^{0.5}$$
(4)

where:

$$a = \frac{0.072 R_b^2}{\sigma}$$

 E_2 = emission factor in grains/ft³ of aeration air; and the other variables are as defined previously.

Equations 3 and 4 also can be used to estimate emissions from electroless plating operations. It should be noted that Equations 1 thorough 4 have not been validated using multiple emission tests and should be used cautiously. Furthermore, the emission factors that are calculated in units of concentration may not be applicable to plating lines in which there are multiple tanks that introduce varying amounts of dilution air to a common control device. Finally, Equation 1 does not take into account the emissions reductions achieved by using fume suppressants. If a fume suppressant is used, the corresponding emission factor for hard chromium plating with fume suppressant control should be used with Equation 2 to estimate emissions. Alternately, Equation 1 can be used and the resulting emissions can be reduced using an assumed control efficiency for hard or decorative chromium electroplating, depending upon which type of plating operation is more similar to the type of plating conducted. The control efficiencies for chemical fume suppressants are 78 percent for hard chromium electroplating controlled and 99.5 percent for decorative chromium plating. Based on the requirements for the chromium electroplating national emission standard, emissions from decorative chromium plating baths with chemical fume suppressants are considered to be controlled if the resulting surface tension is no more than 45 dynes per centimeter (dynes/cm) (3.1 x 10^{-3} pound-force per foot [lb_f/ft]).

Emissions chromium electroplating operations are regulated under the 40 CFR part 63, subpart N, National Emission Standards for Chromium Emissions From Hard and Decorative Chromium Electroplating and Chromium Anodizing Tanks. These standards, which were promulgated on January 25, 1995 (60 FR 4963), limit emissions of total chromium to 0.03 milligrams per dry standard cubic meter (mg/dscm) (1.3 x 10^{-5} grains/dscf) from plating tanks at small, hard chromium electroplating facilities; and to 0.015 mg/dscm (6.6 x 10^{-6} grains/dscf) from all other hard chromium plating tanks. Small, hard chromium plating facilities are defined in the rule as those which have a maximum cumulative rectifier capacity of less than 60 million amp-hr/yr. Total chromium emissions from decorative chromium plating tanks and chromic acid anodizing tanks are limited to 0.01 mg/dscm (4.4 x 10^{-6} grains/dscf), unless a fume suppressant is used and the bath surface tension is maintained at no more than 45 dynes/cm (3.1 x 10^{-3} lb/ft).

	Chromium	Compounds ^b	EMISSION	Total	PM ^c	EMISSION
Process	grains/A-hr	grains/dscf	RATING	grains/A-hr	grains/dscf	RATING
Hard chromium electroplating ^d (SCC 3-09-010-18)	0.12	NA	В	0.25	NA	С
with moisture extractor ^e	NA	0.00014	D	NA	0.00028	Е
with polypropylene balls ^f	NA	0.00042	D	NA	0.00088	Е
with fume suppressant ^g	NA	0.00016	D	NA	0.00034	Е
 with fume suppressant and polypropylene balls^h 	NA	3.0 x 10 ⁻⁵	D	NA	6.3 x 10 ⁻⁵	E
with packed-bed scrubber ^J	NA	2.1 x 10 ⁻⁵	D	NA	4.4 x 10 ⁻⁵	Е
with packed-bed scrubber, fume suppressant, and polypropylene balls ^k	NA	2.6 x 10 ⁻⁶	D	NA	5.5 x 10 ⁻⁶	Е
with chevron-blade mist eliminator ^m	NA	8.8 x 10 ⁻⁵	D	NA	0.00018	Е
with mesh-pad mist eliminator ⁿ	NA	1.2 x 10 ⁻⁵	D	NA	2.6 x 10 ⁻⁵	Е
 with packed-bed scrubber and mesh-pad eliminator^p 	NA	3.2 x 10 ⁻⁸	Е	NA	6.7 x 10 ⁻⁸	Е
 with composite mesh-pad mist eliminator^q 	NA	3.8 x 10 ⁻⁶	D	NA	8.0 x 10 ⁻⁶	Е
Decorative chromium electroplating ^r (SCC 3-09-010-28)	0.033	NA	D	0.069	NA	E
with fume suppressant ^s	NA	1.2 x 10 ⁻⁶	D	NA	2.5 x 10 ⁻⁶	Е

Table 12.20-1. EMISSION FACTORS FOR CHROMIUM ELECTROPLATING^a

^a For chromium electroplating tanks only. Factors represent uncontrolled emissions unless otherwise noted. Emission factors based on total energy input in units of grains per ampere-hour (grains/A-hr) and based on concentrations in units of grains per dry standard cubic foot (grains/dscf). To convert from grains/A-hr to mg/A-hr multiply by 64.8. To convert grains/dscf to mg/dscm, multiply by 2,290. To convert grains/A-hr to grains/dscf, multiply by 0.01. To convert grains/dscf to grains/dscf to grains/A-hr multiply by 100. Note that there is considerable uncertainty in these latter two conversion factors because of differences in tank geometry, ventilation, and control device performance. For controlled emissions, factors based on concentration should be used whenever possible. SCC = Source Classification Code. NA = units not applicable.

^b Comprised almost completely of hexavalent chromium.

^c Total PM includes filterable and condensible PM. However, condensible PM is likely to be negligible. All PM from chromium electroplating sources is likely to be emitted as PM-10. Factors estimated based on assumption that PM consists entirely of chromic acid mist.

- ^d References 5-13,15,17-18,23-25,28,34.
- ^e References 8,14.
- f Reference 10.
- ^g Reference 15.
- ^h References 18,23-25.
- ^j References 11-13,18,32,34-35.
- ^k References 18, 40-42.
- ^m References 5-7.
- ⁿ References 8-10,21,28.
- ^p Reference 37.
- ^q References 11-13.
- ^r References 19-20,25-26.
- ^s References 20, 25-26.

Process	Chromium Compounds, ^b grains/hr-ft ²	EMISSION FACTOR RATING	Total PM, ^c grains/hr-ft ²	EMISSION FACTOR RATING
Chromic acid anodizing ^d (SCC 3-09-010-38)	2.0	D	4.2	Е
with polypropylene balls ^e	1.7	D	3.6	Ε
with fume suppressant ^f	0.064	D	0.13	Е
with fume suppressant and polypropylene balls ^g	0.025	D	0.053	Ε
with packed-bed scrubber ^h	0.0096	D	0.020	Е
with packed-bed scrubber and fume suppressant ^d	0.00075	D	0.0016	E
with mesh-pad mist eliminator ^k	0.0051	Е	0.011	Е
with packed-bed scrubber and mesh pad mist eliminator ^m	0.00054	D	0.0011	Е
with wet scrubber, moisture extractor, and high efficiency particulate air filter ⁿ	0.00048	D	0.0010	Е

Table 12.20-2. EMISSION FACTORS FOR CHROMIC ACID ANODIZING^a

- ^a For chromium electroplating tanks only. Factors represent uncontrolled emissions unless otherwise noted. Factors are in units of grains per hour per square foot (grains/hr-ft²) of tank surface area. SCC = Source Classification Code. To convert from grains/hr-ft² to mg/hr-m², multiply by 0.70.
- ^b Comprised almost completely of hexavalent chromium.
- ^c Total PM includes filterable and condensible PM. However, condensible PM is likely to be negligible. All PM from chromium electroplating sources is likely to be emitted as PM-10. Factors estimated based on assumption that PM consists entirely of chromic acid mist.
- ^d References 27,29-30,33,42.

^e Reference 30.

- f References 27,29-30.
- ^g References 27,30.
- ^h References 33,39.
- ^j Reference 36.
- ^k Reference 21.
- ^m Reference 37.
- ⁿ Reference 42.

Table 12.20-3. SUMMARY OF PARTICLE SIZE DISTRIBUTIONS FOR CHROMIUM ELECTROPLATING^a

	Uncontrolled	l	Controlled ^b				
	Cumulative Pe	rcent Less Than	_	Cumulative P	ercent Less Than		
Diameter, µm	Total PM ^c	Chromium Compounds ^d	Diameter, µm	Total PM ^c	Chromium Compounds ^d		
<0.5	0	0	<0.49	0	0		
0.5	9.1	6.9	0.49	18.5	20.4		
2.4	48.3	67.7	2.35	94.7	97.5		
8.0	59.3	82.6	7.9	100	99.2		

^a Reference 6. Based on C-rated emission data for hard chromium electroplating tanks. Source Classification Code 3-09-010-18.

^b Controlled with chevron-blade mist eliminators.

^c Total PM consists of filterable and condensible PM. However, condensible PM is likely to be negligible.

^d Comprised almost completely of hexavalent chromium.

Table 12.20-4. EMISSION FACTORS FOR ELECTROPLATING--OTHER METALS^a EMISSION FACTOR RATING: E

		Emissio	n Factor	Def
Source	Pollutant	grains/A-hr	grains/dscf	Ker.
Copper cyanide electroplating tank with mesh-pad mist eliminator (SCC 3-09-010-42)	Cyanide	NA	2.7 x 10 ⁻⁶	21
Copper sulfate electroplating tank with wet scrubber (SCC 3-09-010-45)	Copper	NA	8.1 x 10 ⁻⁵	31
Cadmium cyanide electroplating tank (SCC 3-09-010-52)	Cadmium	0.040	NA	31
with mesh-pad mist eliminator	Cyanide	NA	0.00010	21
with mesh-pad mist eliminator	Cadmium	NA	1.4 x 10 ⁻⁷	21
with packed-bed scrubber	Cyanide	NA	5.9 x 10 ⁻⁵	22
with packed-bed scrubber	Cadmium	NA	1.7 x 10 ⁻⁶	22, 31
with packed-bed scrubber	Ammonia	NA	4.2 x 10 ⁻⁵	22
Nickel electroplating tank (SCC 3-09-010-68)	Nickel	0.63	NA	31
with wet scrubber	Nickel	NA	6.7 x 10 ⁻⁶	31

^a Factors represent uncontrolled emissions unless noted. All emission factors in units of grains per ampere-hour (grains/A-hr) and as concentrations in units of grains per dry standard cubic foot (grains/dscf). To convert from grains/A-hr to mg/A-hr multiply by 64.8. To convert grains/dscf to mg/dscm, multiply by 2,290. To convert grains/A-hr to grains/dscf, multiply by 0.01. To convert grains/dscf to grains/dscf to grains/A-hr multiply by 100. Note that there is considerable uncertainty in these latter two conversion factors because of differences in tank geometry, ventilation, and control device performance. SCC = Source Classification Code. NA = units not applicable.

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13. MISCELLANEOUS SOURCES

This chapter contains emission factor information on those source categories that differ substantially from, and hence cannot be grouped with, the other "stationary" sources discussed in this publication. Most of these miscellaneous emitters, both natural and manmade, are truly area sources, with their pollutant-generating process(es) dispersed over large land areas. Another characteristic of these sources is the inapplicability, in most cases, of conventional control methods such as wet/dry equipment, fuel switching, process changes, etc. Instead, control of these emissions, where possible at all, may involve such techniques as modification of agricultural burning practices, paving with asphalt or concrete, or stabilization of dirt roads. Finally, miscellaneous sources generally emit pollutants intermittently, compared to most stationary point sources. For example, a wildfire may emit large quantities of particulate and carbon monoxide for several hours or even days. But, when measured against a continuous emitter over a long period of time its emissions may seem relatively minor. Also, effects on air quality may be of relatively short duration.

13.1 Wildfires And Prescribed Burning

13.1.1 General¹

A wildfire is a large-scale natural combustion process that consumes various ages, sizes, and types of flora growing outdoors in a geographical area. Consequently, wildfires are potential sources of large amounts of air pollutants that should be considered when trying to relate emissions to air quality.

The size and intensity, even the occurrence, of a wildfire depend directly on such variables as meteorological conditions, the species of vegetation involved and their moisture content, and the weight of consumable fuel per acre (available fuel loading). Once a fire begins, the dry combustible material is consumed first. If the energy release is large and of sufficient duration, the drying of green, live material occurs, with subsequent burning of this material as well. Under proper environmental and fuel conditions, this process may initiate a chain reaction that results in a widespread conflagration.

The complete combustion of wildland fuels (forests, grasslands, wetlands) require a heat flux (temperature gradient), adequate oxygen supply, and sufficient burning time. The size and quantity of wildland fuels, meteorological conditions, and topographic features interact to modify the burning behavior as the fire spreads, and the wildfire will attain different degrees of combustion efficiency during its lifetime.

The importance of both fuel type and fuel loading on the fire process cannot be overemphasized. To meet the pressing need for this kind of information, the U. S. Forest Service is developing a model of a nationwide fuel identification system that will provide estimates of fuel loading by size class. Further, the environmental parameters of wind, slope, and expected moisture changes have been superimposed on this fuel model and incorporated into a National Fire Danger Rating System (NFDRS). This system considers five classes of fuel, the components of which are selected on the basis of combustibility, response of dead fuels to moisture, and whether the living fuels are herbaceous (grasses, brush) or woody (trees, shrubs).

Most fuel loading figures are based on values for "available fuel", that is, combustible material that will be consumed in a wildfire under specific weather conditions. Available fuel values must not be confused with corresponding values for either "total fuel" (all the combustible material that would burn under the most severe weather and burning conditions) or "potential fuel" (the larger woody material that remains even after an extremely high intensity wildfire). It must be emphasized, however, that the various methods of fuel identification are of value only when they are related to the existing fuel quantity, the quantity consumed by the fire, and the geographic area and conditions under which the fire occurs.

For the sake of conformity and convenience, estimated fuel loadings estimated for the vegetation in the U. S. Forest Service Regions are presented in Table 13.1-1. Figure 13.1-1 illustrates these areas and regions.

Miscellaneous Sources

	Estimated Avera	ge Fuel Loading
National Region ^b	Mg/hectare	ton/acre
Rocky Mountain	83	37
Region 1: Northern	135	60
Region 2: Rocky Mountain	67	30
Region 3: Southwestern	22	10
Region 4: Intermountain	40	8
Pacific	43	19
Region 5: California	40	18
Region 6: Pacific Northwest	135	60
Region 10: Alaska	36	16
Coastal	135	60
Interior	25	11
Southern	20	9
Region 8: Southern	20	9
Eastern	25	11
North Central	25	11
Region 9: Conifers	22	10
Hardwoods	27	12

Table 13.1-1	(Metric And English Units).	SUMMARY OF ESTIMATED FUEL CONSUMED BY
		WILDFIRES [*]

^a Reference 1.

^b See Figure 13.1-1 for region boundaries.

13.1.2 Emissions And Controls¹

It has been hypothesized, but not proven, that the nature and amounts of air pollutant emissions are directly related to the intensity and direction (relative to the wind) of the wildfire, and are indirectly related to the rate at which the fire spreads. The factors that affect the rate of spread are (1) weather (wind velocity, ambient temperature, relative humidity); (2) fuels (fuel type, fuel bed array, moisture content, fuel size); and (3) topography (slope and profile). However, logistical problems (such as size of the burning area) and difficulties in safely situating personnel and equipment close to the fire have prevented the collection of any reliable emissions data on actual wildfires, so that it is not possible to verify or disprove the hypothesis. Therefore, until such measurements are made, the only available information is that obtained from burning experiments in the laboratory. These data, for both emissions and emission factors, are contained in Table 13.1-2. It must be emphasized that the factors presented here are adequate for laboratory-scale emissions estimates, but that substantial errors may result if they are used to calculate actual wildfire emissions.



Figure 13.1-1. Forest areas And U. S. Forest Service Regions.

The emissions and emission factors displayed in Table 13.1-2 are calculated using the following formulas:

$$\mathbf{F}_{i} = \mathbf{P}_{i}\mathbf{L} \tag{1}$$

$$\mathbf{E}_{i} = \mathbf{F}_{i}\mathbf{A} = \mathbf{P}_{i}\mathbf{L}\mathbf{A} \tag{2}$$

where:

- F_i = emission factor (mass of pollutant/unit area of forest consumed)
- P_i = yield for pollutant "i" (mass of pollutant/unit mass of forest fuel consumed)
 - = 8.5 kilograms per megagram (kg/Mg) (17 pound per ton [lb/ton]) for total particulate
 - = 70 kg/Mg (140 lb/ton) for carbon monoxide
 - = 12 kg/Mg (24 lb/ton) for total hydrocarbon (as CH₄)
 - = 2 kg/Mg (4 lb/ton) for nitrogen oxides (NO_x)
 - = negligible for sulfur oxides (SO_x)
- L = fuel loading consumed (mass of forest fuel/unit land area burned)
- A = land area burned
- E_i = total emissions of pollutant "i" (mass pollutant)

Miscellaneous Sources

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Table 13.1-2. EMISSIONS AND EMISSION FACTORS FOR FOREST WILDFIRES

	Area Consumed	Wilders Fuel	E	Emission Facto	rs (kg/Hectare)		Emission	s (Mg)	
Geographic Area	By Wildfire ^a (hectares)	Consumption (Mg/hectare)	Particulate	Carbon Monoxide	Volatile Organics ^b	Nitrogen Oxides	Particulate	Carbon Monoxide	Volatile Organics ^b	Nitrogen Oxides
Rocky Mountain	313 307	83	706	5 810	996	166	220 907	1 819 237	311 869	51 978
	140.076	125	1 1 4 4	0,420	1 (20	100	160.069	1,017,257	220,502	29.265
Northern (Region 1)	142,276	135	1,144	9,420	1,620	209	102,208	1,339,283	229,392	38,203
Rocky Mountain (Region 2)	65,882	67	572	4,710	808	135	37,654	310,086	53,157	8,860
Southwestern (Region 3)	83,765	22	191	1,570	269	45	15,957	131,417	22,533	3,735
Intermountain (Region 4)	21,475	40	153	1,260	215	36	3,273	26,953	4,620	770
Pacific	469,906	43	362	2,980	512	85	1 70,090	1,400,738	240,126	40,02 1
California (Region 5)	18,997	40	343	2,830	485	81	6,514	53,645	9,196	1,533
Alaska (Region 10)	423,530	36	305	2,510	43 1	72	129,098	1 ,063,154	182,255	30,376
Pacific Northwest (Region 6)	27,380	1 35	1,144	9,420	1 ,620	269	31,296	257,738	44,183	7,363
Southern	806,289	20	1 72	1,410	242	40	138,244	1,138,484	195,168	35,528
Southern (Region 8)	806,289	20	172	1,410	242	40	138,244	1,138,484	195,168	35,528
North Central and Eastern	94,191	25	210	1,730	296	49	19,739	162,555	27,867	4,644
(Region 9)	141,238	25	210	1,730	296	49	29,598	243,746	41,785	6,964
Eastern Group (With Region 9)	47,046	25	210	1,730	296	49	9,859	81,191	13,918	2,320
Total	1,730,830	38	324	2,670	458	76	560,552	4,616,317	791,369	131,895

EMISSION FACTOR RATING: D

^a Consumption data are for 1971.
 ^b Expressed as methane.

For example, suppose that it is necessary to estimate the total particulate emissions from a 10,000-hectare wildfire in the Southern area (Region 8). From Table 13.1-1, it is seen that the average fuel loading is 20 Mg/hectare (9 tons/acre). Further, the pollutant yield for particulates is 8.5 kg/Mg (17 lb/ton). Therefore, the emissions are:

E = (8.5 kg/Mg of fuel) (20 Mg of fuel/hectare) (10,000 hectares)

E = 1,700,000 kg = 1,700 Mg

The most effective method of controlling wildfire emissions is, of course, to prevent the occurrence of wildfires by various means at the land manager's disposal. A frequently used technique for reducing wildfire occurrence is "prescribed" or "hazard reduction" burning. This type of managed burn involves combustion of litter and underbrush to prevent fuel buildup under controlled conditions, thus reducing the danger of a wildfire. Although some air pollution is generated by this preventive burning, the net amount is believed to be a relatively smaller quantity then that produced by wildfires.

13.1.3 Prescribed Burning¹

Prescribed burning is a land treatment, used under controlled conditions, to accomplish natural resource management objectives. It is one of several land treatments, used individually or in combination, including chemical and mechanical methods. Prescribed fires are conducted within the limits of a fire plan and prescription that describes both the acceptable range of weather, moisture, fuel, and fire behavior parameters, and the ignition method to achieve the desired effects. Prescribed fire is a cost-effective and ecologically sound tool for forest, range, and wetland management. Its use reduces the potential for destructive wildfires and thus maintains long-term air quality. Also, the practice removes logging residues, controls insects and disease, improves wildlife habitat and forage production, increases water yield, maintains natural succession of plant communities, and reduces the need for pesticides and herbicides. The major air pollutant of concern is the smoke produced.

Smoke from prescribed fires is a complex mixture of carbon, tars, liquids, and different gases. This open combustion source produces particles of widely ranging size, depending to some extent on the rate of energy release of the fire. For example, total particulate and particulate less than 2.5 micrometers (μ m) mean mass cutpoint diameters are produced in different proportions, depending on rates of heat release by the fire.² This difference is greatest for the highest-intensity fires, and particle volume distribution is bimodal, with peaks near 0.3 μ m and exceeding 10 μ m.³ Particles over about 10 μ m, probably of ash and partially burned plant matter, are entrained by the turbulent nature of high-intensity fires.

Burning methods differ with fire objectives and with fuel and weather conditions.⁴ For example, the various ignition techniques used to burn under standing trees include: (1) heading fire, a line of fire that runs with the wind; (2) backing fire, a line of fire that moves into the wind; (3) spot fires, which burn from a number of fires ignited along a line or in a pattern; and (4) flank fire, a line of fire that is lit into the wind, to spread laterally to the direction of the wind. Methods of igniting the fires depend on forest management objectives and the size of the area. Often, on areas of 50 or more acres, helicopters with aerial ignition devices are used to light broadcast burns. Broadcast fires may involve many lines of fire in a pattern that allows the strips of fire to burn together over a sizeable area.

In discussing prescribed burning, the combustion process is divided into preheating, flaming, glowing, and smoldering phases. The different phases of combustion greatly affect the amount of emissions produced.⁵⁻⁷ The preheating phase seldom releases significant quantities of material to the atmosphere. Glowing combustion is usually associated with burning of large concentrations of woody fuels such as logging residue piles. The smoldering combustion phase is a very inefficient and incomplete combustion process that emits pollutants at a much higher ratio to the quantity of fuel consumed than does the flaming combustion of similar materials.

The amount of fuel consumed depends on the moisture content of the fuel.⁸⁻⁹ For most fuel types, consumption during the smoldering phase is greatest when the fuel is driest. When lower layers of the fuel are moist, the fire usually is extinguished rapidly.¹⁰

The major pollutants from wildland burning are particulate, carbon monoxide, and volatile organics. Nitrogen oxides are emitted at rates of from 1 to 4 g/kg burned, depending on combustion temperatures. Emissions of sulfur oxides are negligible.¹¹⁻¹²

Particulate emissions depend on the mix of combustion phase, the rate of energy release, and the type of fuel consumed. All of these elements must be considered in selecting the appropriate emission factor for a given fire and fuel situation. In some cases, models developed by the U. S. Forest Service have been used to predict particulate emission factors and source strength.¹³ These models address fire behavior, fuel chemistry, and ignition technique, and they predict the mix of combustion products. There is insufficient knowledge at this time to describe the effect of fuel chemistry on emissions.

Table 13.1-3 presents emission factors from various pollutants, by fire and fuel configuration. Table 13.1-4. gives emission factors for prescribed burning, by geographical area within the United States. Estimates of the percent of total fuel consumed by region were compiled by polling experts from the Forest Service. The emission factors are averages and can vary by as much as 50 percent with fuel and fire conditions. To use these factors, multiply the mass of fuel consumed per hectare by the emission factor for the appropriate fuel type. The mass of fuel consumed by a fire is defined as the available fuel. Local forestry officials often compile information on fuel consumption for prescribed fires and have techniques for estimating fuel consumption under local conditions. The Southern Forestry Smoke Management Guidebook⁵ and the Prescribed Fire Smoke Management Guide¹⁵ should be consulted when using these emission factors.

The regional emission factors in Table 13.1-4 should be used only for general planning purposes. Regional averages are based on estimates of the acreage and vegetation type burned and may not reflect prescribed burning activities in a given state. Also, the regions identified are broadly defined, and the mix of vegetation and acres burned within a given state may vary considerably from the regional averages provided. Table 13.1-4 should not be used to develop emission inventories and control strategies.

To develop state emission inventories, the user is strongly urged to contact that state's federal land management agencies and state forestry agencies that conduct prescribed burning to obtain the best information on such activities.

		Pollutant (g/kg)							
			Particulate		Gutter	Volatile Organics		Eucl Mir	EMISSION
Fire/Fuel Configuration	Phase	PM-2.5	PM-10	Total	Monoxide	Methane	Nonmethane	(%)	RATING
Broadcast logging slash									
Hardwood	F	6	7 ⁶	13	44	2.1	3.8	33	A
	s	13	14 ^b	20	146	8.0	7.7	67	A
	Fire	11	12 ^b	18	112	6.1	6.4		A
Conifer	-								
Short needle	F	7	8°	12	72	2.3	2.1	33	A
	s	14	1 5°	1 9	226	7.2	4.2	67	A
	Fire	12	1 3 °	17	17 5	5.6	3.5		A
Long needle	F	6	6 ^d	9	45	1.5	1.7	33	В
i -	s	16	17 ^d	25	166	7.7	5.4	67	В
	Fire	13	13 ^d	20	126	5.7	4.2		В
Logging slash debris									
Dozer piled conifer									
No mineral soil ^d	F	4	4	5	28	1.0	ND	90	В
	s	6	7	14	116	8.7	ND	10	В
	Fire	4	4	6	37	1.8	ND		В

Table 13.1-3 (Metric Units). EMISSION FACTORS FOR PRESCRIBED BURNING^a

Table 13.1-3 (cont.).

		Pollutant (g/kg)							
			Particulate		Cathon	Volatile	Organics	Eucl Mer	EMISSION
Fire/Fuel Configuration	Phase	PM-2.5	PM-10	Total	Monoxide	Methane	Nonmethane	(%)	RATING
10 to 30% Mineral soil ^e	S	ND	ND	25	200	ND	ND	ND	D
25% Organic soil ^e	S	ND	ND	35	250	ND	ND	ND	D
Range fire									
Juniper slash ^f	F	7	8	11	41	2.0	2.7	8.2	В
	S	12	13	18	125	10.3	7.8	15.6	В
	Fire ^g	9	10	14	82	6.0	5.2	12.5	В
Sagebrush ^f	F	15	16	23	78	3.7	3.4		В
	S	13	15	23	106	6.2	7.3		В
	Fire ^s	13	15	23	103	6.2	6.9		В
Chaparral shrub communities ^h	F	7	8	16	56	1.7	8.2		А
	S	12	13	23	133	6.4	15.6		А
	Fire	10	11	20	101	4.5	12.5		A
Line fire									
Conifer									
Long needle (pine)	Heading ⁱ	ND	40	50	200	ND	ND		D
	Backing ^k	ND	20	20	125	ND	ND		D
Palmetto/gallberry ^j	Heading	ND	15	17	150	ND	ND		D
	Backing	ND	15	15	100	ND	ND		D
	Fire	ND	8 - 22	ND	ND	ND	ND		D
Chaparral ^k	Heading	8	9	15	62	2.8	3.5		С
Grasslands ⁱ	Fire	ND	10	10	75	ND	0		D

- * References 7-8. Unless otherwise noted, determined by field testing of fires ≥ 1 acre size. F = flaming. S = smoldering. Fire = weighted average of F and S. ND = no data.
- ^b For PM-10, Reference 7. EMISSION FACTOR RATING: C.
- [°] For PM-10, References 3,7. EMISSION FACTOR RATING: D.
- ^d For PM-10, References 3,7. EMISSION FACTOR RATING: D.
- * Reference 12. Determined using laboratory combustion hood.
- ^f Reference 16.
- ^g Fuel mix uncertain, because of short, intense flaming phase. Use fire average for emission inventory purposes.
- ^h References 17-18.
- ^j References 13-14. Determined using laboratory combustion hood.
- ^k References 13-14.

			Pollu	tant°	
Pagional Configuration	Dorcont	Pa	rticulate (g/k	g)	
And Fuel Type ^a	Of Fuel ^b	PM-2.5	PM-10	РМ	СО
Pacific Northwest					
Logging slash					
Piled slash	42	4	5	6	37
Douglas fir/Western hemlock	24	12	13	17	175
Mixed conifer	19	12	13	17	175
Ponderosa pine	6	13	13	20	126
Hardwood	4	11	12	18	112
Underburning pine	5	30	30	35	163
Average for region	100	9.4	10.3	13.3	111.1
Pacific Southwest					
Sagebrush	35		9	15	62
Chaparral	20	8	9	15	62
Pinyon/Juniper	20		13	17	175
Underburning pine	15		30	35	163
Grassland	10		10	10	15
Average for region	100		13.0	17.8	101.0
Southeast					
Palmetto/gallbery	35		15	16	125
Underburning pine	30		30	35	163
Logging slash	20		13	20	126
Grassland	10		10	10	75
Other	5		17	17	175
Average for region	100		18.8	21.9	134

Table 13.1-4 (Metric Units).EMISSION FACTORS FOR PRESCRIBED BURNING
BY U. S. REGION

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Table 13.1-4 (cont.)	Table	13.	1-4	(cont.)	
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			Pollut	tant°	
Pagianal Configuration	Doroont	Pa	rticulate (g/k	g)	
And Fuel Type ^a	of Fuel ^b	PM-2.5	PM-10	РМ	CO
Rocky Mountain					
Logging slash	50		4	6	37
Underburning pine	20		30	35	163
Grassland	20		10	10	75
Other	10		17	17	175
Average for region	100		11.9	13.7	83.4
North Central and Eastern					
Logging slash	50		13	17	175
Grassland	30		10	10	75
Underburning pine	10		30	35	163
Other	10		17	17	175
Average for region	100		14	16.5	143.8

^a Regional areas are generalized, e. g., the Pacific Northwest includes Oregon, Washington, and parts of Idaho and California. Fuel types generally reflect the ecosystems of a region, but users should seek advice on fuel type mix for a given season of the year. An average factor for Northern California could be more accurately described as chaparral, 25%; underburning pine, 15%; sagebrush, 15%; grassland, 5%; mixed conifer, 25%; and douglas fir/Western hemlock, 15%. Blanks indicate no data.

^b Based on the judgement of forestry experts.

[°] Adapted from Table 13.1-3 for the dominant fuel types burned.

13.1.4 Wildfires and Prescribed Burning-Greenhouse Gases

Emission factors for greenhouse gases from wildfires and prescribed burning are provided based on the amount of material burned. Emission factors for methane (CH₄) and nitrous oxide (N₂O) based on the mass of material burned are provided in Table 13.1-5. To express emissions based on area burned, refer to Table 13.1-1 for estimated average fuel loading by region. The CH₄ emission factors have been divided into the type of forests being studied for specific plant species. Emissions of CO₂ from this source as well as other biogenic sources are part of the carbon cycle, and as such are typically not included in greenhouse gas emission inventories.

Table 13.1-5. WILDFIRE AND PRESCRIBED BURNING GREENHOUSE GAS EMISSION FACTORS

	Pollutant (lb/ton)			
Regional/Fuel Type [®]	CH₄	N ₂ O		
Agricultural Residues	5.4 ^b			
Amazon	8.5°			
Boreal and Coniferous Forests	11.1°	0.46		
Savanna	3.7°			
Temperate and Boreal Forests	12.2			

EMISSION FACTOR RATING: C

^a References 19-22. To convert lb/ton to kg/Mg multiply by 0.5.

^b For more details see Table 2.5-5 of Section 2.5 Opening Burning.

[°] Emission factor developed based on combustion efficiency (ratio of carbon released as CO₂).

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13.2 Fugitive Dust Sources

Significant atmospheric dust arises from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream. Common sources of fugitive dust include unpaved roads, agricultural tilling operations, aggregate storage piles, and heavy construction operations.

For the above sources of fugitive dust, the dust-generation process is caused by 2 basic physical phenomena:

- 1. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.).
- 2. Entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface by wind speeds over 19 kilometers per hour (km/hr) (12 miles per hour [mph]).

In this section of AP-42, the principal pollutant of interest is PM-10 — particulate matter (PM) no greater than 10 micrometers in aerodynamic diameter (μ mA). Because PM-10 is the size basis for the current primary National Ambient Air Quality Standards (NAAQS) for particulate matter, it represents the particle size range of the greatest regulatory interest. Because formal establishment of PM-10 as the primary standard basis occurred in 1987, many earlier emission tests have been referenced to other particle size ranges, such as:

- TSP Total Suspended Particulate, as measured by the standard high-volume ("hi-vol") air sampler, has a relatively coarse size range. TSP was the basis for the previous primary NAAQS for PM and is still the basis of the secondary standard. Wind tunnel studies show that the particle mass capture efficiency curve for the high-volume sampler is very broad, extending from 100 percent capture of particles smaller than 10 μ m to a few percent capture of particles as large as 100 μ m. Also, the capture efficiency curve varies with wind speed and wind direction, relative to roof ridge orientation. Thus, high-volume samplers do not provide definitive particle size information for emission factors. However, an effective cut point of 30 μ m aerodynamic diameter is frequently assigned to the standard high volume sampler.
- SP Suspended Particulate, which is often used as a surrogate for TSP, is defined as PM with an aerodynamic diameter no greater than 30 μ m. SP may also be denoted as PM-30.
- IP Inhalable Particulate is defined as PM with an aerodynamic diameter no greater than $15 \ \mu m$ IP also may be denoted as PM-15.
- FP Fine Particulate is defined as PM with an aerodynamic diameter no greater than $2.5 \ \mu m$. FP may also be denoted as PM-2.5.

The impact of a fugitive dust source on air pollution depends on the quantity and drift potential of the dust particles injected into the atmosphere. In addition to large dust particles that settle out near the source (often creating a local nuisance problem), considerable amounts of fine particles also are emitted and dispersed over much greater distances from the source. PM-10 represents a relatively fine particle size range and, as such, is not overly susceptible to gravitational settling.

The potential drift distance of particles is governed by the initial injection height of the particle, the terminal settling velocity of the particle, and the degree of atmospheric turbulence. Theoretical drift distance, as a function of particle diameter and mean wind speed, has been computed for fugitive dust emissions. Results indicate that, for a typical mean wind speed of 16 km/hr (10 mph), particles larger than about 100 μ m are likely to settle out within 6 to 9 meters (20 to 30 feet [ft]) from the edge of the road or other point of emission. Particles that are 30 to 100 μ m in diameter are likely to undergo impeded settling. These particles, depending upon the extent of atmospheric turbulence, are likely to settle within a few hundred feet from the road. Smaller particles, particularly IP, PM-10, and FP, have much slower gravitational settling velocities and are much more likely to have their settling rate retarded by atmospheric turbulence.

Control techniques for fugitive dust sources generally involve watering, chemical stabilization, or reduction of surface wind speed with windbreaks or source enclosures. Watering, the most common and, generally, least expensive method, provides only temporary dust control. The use of chemicals to treat exposed surfaces provides longer dust suppression, but may be costly, have adverse effects on plant and animal life, or contaminate the treated material. Windbreaks and source enclosures are often impractical because of the size of fugitive dust sources.

The reduction of source extent and the incorporation of process modifications or adjusted work practices, both of which reduce the amount of dust generation, are preventive techniques for the control of fugitive dust emissions. These techniques could include, for example, the elimination of mud/dirt carryout on paved roads at construction sites. On the other hand, mitigative measures entail the periodic removal of dust-producing material. Examples of mitigative control measures include clean-up of spillage on paved or unpaved travel surfaces and clean-up of material spillage at conveyor transfer points.

13.2.1 Paved Roads

13.2.1.1 General

Particulate emissions occur whenever vehicles travel over a paved surface, such as a road or parking lot. In general terms, particulate emissions from paved roads originate from the loose material present on the surface. In turn, that surface loading, as it is moved or removed, is continuously replenished by other sources. At industrial sites, surface loading is replenished by spillage of material and trackout from unpaved roads and staging areas. Figure 13.2.1-1 illustrates several transfer processes occurring on public streets.

Various field studies have found that public streets and highways, as well as roadways at industrial facilities, can be major sources of the atmospheric particulate matter within an area.¹⁻⁹ Of particular interest in many parts of the United States are the increased levels of emissions from public paved roads when the equilibrium between deposition and removal processes is upset. This situation can occur for various reasons, including application of snow and ice controls, carryout from construction activities in the area, and wind and/or water erosion from surrounding unstabilized areas.

13.2.1.2 Emissions And Correction Parameters

Dust emissions from paved roads have been found to vary with what is termed the "silt loading" present on the road surface as well as the average weight of vehicles traveling the road. The term silt loading (sL) refers to the mass of silt-size material (equal to or less than 75 micrometers $[\mu m]$ in physical diameter) per unit area of the travel surface.⁴⁻⁵ The total road surface dust loading is that of loose material that can be collected by broom sweeping and vacuuming of the traveled portion of the paved road. The silt fraction is determined by measuring the proportion of the loose dry surface dust that passes through a 200-mesh screen, using the ASTM-C-136 method. Silt loading is the product of the silt fraction and the total loading, and is abbreviated "sL". Additional details on the sampling and analysis of such material are provided in AP-42 Appendices C.1 and C.2.

The surface sL provides a reasonable means of characterizing seasonal variability in a paved road emission inventory.⁹ In many areas of the country, road surface loadings are heaviest during the late winter and early spring months when the residual loading from snow/ice controls is greatest.

13.2.1.3 Predictive Emission Factor Equations¹⁰

The quantity of dust emissions from vehicle traffic on a paved road may be estimated using the following empirical expression:

$$E = k (sL/2)^{0.65} (W/3)^{1.5}$$
(1)

where:

E = particulate emission factor

k = base emission factor for particle size range and units of interest (see below)

sL = road surface silt loading (grams per square meter) (g/m²)

W = average weight (tons) of the vehicles traveling the road

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Figure 13.2.1-1. Deposition and removal processes.

It is important to note that Equation 1 calls for the average weight of all vehicles traveling the road. For example, if 99 percent of traffic on the road are 2 Mg cars/trucks while the remaining 1 percent consists of 20 Mg trucks, then the mean weight "W" is 2.2 Mg. More specifically, Equation 1 is *not* intended to be used to calculate a separate emission factor for each vehicle weight class. Instead, only 1 emission factor should be calculated to represent the "fleet" average weight of all vehicles traveling the road.

The particle size multiplier (k) above varies with aerodynamic size range as follows:

	Multiplier k ^b					
Size Range ^a	g/VKT	g/VMT	lb/VMT			
PM-2.5	2.1	3.3	0.0073			
PM-10	4.6	7.3	0.016			
PM-15	5.5	9.0	0.020			
PM-30 ^c	24	38	0.082			

^a Refers to airborne particulate matter (PM-x) with an aerodynamic diameter equal to or less than x micrometers.

^b Units shown are grams per vehicle kilometer traveled (g/VKT), grams per vehicle mile traveled (g/VMT), and pounds per vehicle mile traveled (lb/VMT).

^c PM-30 is sometimes termed "suspendable particulate" (SP) and is often used as a surrogate for TSP.

To determine particulate emissions for a specific particle size range, use the appropriate value of k above.

The above equation is based on a regression analysis of numerous emission tests, including 65 tests for PM-10.¹⁰ Sources tested include public paved roads, as well as controlled and uncontrolled industrial paved roads. No tests of "stop-and-go" traffic were available for inclusion in the data base. The equations retain the quality rating of A (B for PM-2.5), if applied within the range of source conditions that were tested in developing the equation as follows:

Silt loading:	0.02 - 0.03 -	400 g/m ² 570 grains/square foot (ft ²)
Mean vehicle weight:	1.8 - 2.0 -	38 megagrams (Mg) 42 tons
Mean vehicle speed:	16 - 10 -	88 kilometers per hour (kph) 55 miles per hour (mph)

To retain the quality rating for the emission factor equation when it is applied to a specific paved road, it is necessary that reliable correction parameter values for the specific road in question be determined. The field and laboratory procedures for determining surface material silt content and surface dust loading are summarized in Appendices C.1 and C.2. In the event that site-specific values cannot be obtained, an appropriate value for an industrial road may be selected from the mean values given in Table 13.2.1-1, but the quality rating of the equation should be reduced by 1 level. Also, recall that Equation 1 refers to emissions due to freely flowing (not stop-and-go) traffic.

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Table 13.2.1-1 (Metric And English Units).	TYPICAL SILT CONTENT AND LOADING VALUES FOR PAVED ROADS AT
	INDUSTRIAL FACILITIES ^a

			Silt Content (%) No. Of		Total L	Total Loading x 10^{-3}			Silt Loading (g/m ²)	
Industry	Sites	Samples	Range	Mean	Lanes	Range	Mean	Units ^b	Range	Mean
Copper smelting	1	3	15.4-21.7	19.0	2	12.9-19.5 45.8-69.2	15.9 55.4	kg/km lb/mi	188-400	292
Iron and steel production	9	48	1.1-35.7	12.5	2	0.006-4.77 0.020-16.9	0.495 1.75	kg/km lb/mi	0.09-79	9.7
Asphalt batching	1	3	2.6-4.6	3.3	1	12.1-18.0 43.0-64.0	14.9 52.8	kg/km lb/mi	76-193	120
Concrete batching	1	3	5.2-6.0	5.5	2	1.4-1.8 5.0-6.4	1.7 5.9	kg/km lb/mi	11-12	12
Sand and gravel processing	1	3	6.4-7.9	7.1	1	2.8-5.5 9.9-19.4	3.8 13.3	kg/km lb/mi	53-95	70
Municipal solid waste landfill	2	7		-	2	_		_	1.1-32.0	7.4
Quarry	1	6			2				2.4-14	8.2

^a References 1-2,5-6,10-12. Values represent samples collected from *industrial* roads. Public road silt loading values are presented in Figure 13.2.1-2, Figure 13.2.1-3, Figure 13.2.1-4, Figure 13.2.1-5, Figure 13.2.1-6, and Figure 13.2.1-7, and Tables 13.2.1-2 and 13.2.1-3. Dashes indicate information not available.

^b Multiply entries by 1000 to obtain stated units; kilograms per kilometer (kg/km) and pounds per mile (lb/mi).

With the exception of limited access roadways, which are difficult to sample, the collection and use of site-specific sL data for public paved road emission inventories are strongly recommended. Although hundreds of public paved road sL measurements have been made since 1980,^{8, 14-21} uniformity has been lacking in sampling equipment and analysis techniques, in roadway classification schemes, and in the types of data reported.¹⁰ The assembled data set (described below) does not yield any readily identifiable, coherent relationship between sL and road class, average daily traffic (ADT), etc., even though an inverse relationship between sL and ADT had been found for a subclass of curbed paved roads in urban areas.⁸ The absence of such a relationship in the composite data set is believed to be due to the blending of data (industrial and nonindustrial, uncontrolled, and controlled, and so on). Further complicating any analysis is the fact that, in many parts of the country, paved road sL varies greatly over the course of the year, probably because of cyclic variations in mud/dirt carryout and in use of anti-skid materials. For example, repeated sampling of the same roads over a period of 3 calendar years at 4 Montana municipalities indicated a noticeable annual cycle. In those areas, silt loading declines during the first 2 calendar quarters and increases during the fourth quarter.

Figure 13.2.1-2 and Figure 13.2.1-3 present the cumulative frequency distribution for the public paved road sL data base assembled during the preparation of this AP-42 section.¹⁰ The data base includes samples taken from roads that were treated with sand and other snow/ice controls. Roadways are grouped into high- and low-ADT sets, with 5000 vehicles per day being the approximate cutpoint. Figure 13.2.1-2 and Figure 13.2.1-3, respectively, present the cumulative frequency distributions for high- and low-ADT roads.

In the absence of site-specific sL data to serve as input to a public paved road inventory, conservatively high emission estimates can be obtained by using the following values taken from the figures. For annual conditions, the median sL values of 0.4 g/m^2 can be used for high-ADT roads (excluding limited access roads that are discussed below) and 2.5 g/m^2 for low-ADT roads. Worst-case loadings can be estimated for high-ADT (excluding limited access roads) and low-ADT roads, respectively, with the 90th percentile values of 7 and 25 g/m². Figure 13.2.1-4, Figure 13.2.1-5, Figure 13.2.1-6, and Figure 13.2.1-7 present similar cumulative frequency distribution information for high- and low-ADT roads, except that the sets were divided based on whether the sample was collected during the first or second half of the year. Information on the 50th and 90th percentile values is summarized in Table 13.2.1-2.

	High-ADT Roads		Low-ADT Roads		
Averaging Period	50th	90th	50th	90th	
Annual	0.4	7	2.5	25	
January-June	0.5	14	3	30	
July-December	0.3	3	1.5	5	

Table 13.2.1-2 (Metric Units). PERCENTILES FOR NONINDUSTRIAL SILT LOADING (g/m²) DATA BASE

In the event that sL values are taken from any of the cumulative frequency distribution figures, the quality ratings for the emission estimates should be downgraded 2 levels.

As an alternative method of selecting sL values in the absence of site-specific data, users can review the public (i. e., nonindustrial) paved road sL data base presented in Table 13.2.1-3 and can select values that are appropriate for the roads and seasons of interest. Table 13.2.1-3 presents paved road surface loading values together with the city, state, road name, collection date (samples collected from the same road during the same month are averaged), road ADT if reported, classification of the roadway, etc. Recommendation of this approach recognizes that end users of AP-42 are capable of identifying roads in the data base that are similar to roads in the area being inventoried. In the event that sL values are developed in this way, and that the selection process is fully described, then the quality ratings for the emission estimates should be downgraded only 1 level.

Limited access roadways pose severe logistical difficulties in terms of surface sampling, and few sL data are available for such roads. Nevertheless, the available data do not suggest great variation in sL for limited access roadways from 1 part of the country to another. For annual conditions, a default value of 0.02 g/m^2 is recommended for limited access roadways. Even fewer of the available data correspond to worst-case situations, and elevated loadings are observed to be quickly depleted because of high ADT rates. A default value of 0.1 g/m^2 is recommended for short periods of time following application of snow/ice controls to limited access roads.

13.2.1.4 Controls^{6,22}

Because of the importance of the surface loading, control techniques for paved roads attempt either to prevent material from being deposited onto the surface (preventive controls) or to remove from the travel lanes any material that has been deposited (mitigative controls). Regulations requiring the covering of loads in trucks, or the paving of access areas to unpaved lots or construction sites, are preventive measures. Examples of mitigative controls include vacuum sweeping, water flushing, and broom sweeping and flushing.

In general, preventive controls are usually more cost effective than mitigative controls. The cost-effectiveness of mitigative controls falls off dramatically as the size of an area to be treated increases. That is to say, the number and length of public roads within most areas of interest preclude any widespread and routine use of mitigative controls. On the other hand, because of the more limited scope of roads at an industrial site, mitigative measures may be used quite successfully (especially in situations where truck spillage occurs). Note, however, that public agencies could make effective use of mitigative controls to remove sand/salt from roads after the winter ends.

Because available controls will affect the sL, controlled emission factors may be obtained by substituting controlled silt loading values into the equation. (Emission factors from controlled industrial roads were used in the development of the equation.) The collection of surface loading samples from treated, as well as baseline (untreated), roads provides a means to track effectiveness of the controls over time.



Figure 13.2.1-2. Cumulative frequency distribution for surface silt loading on high-ADT roadways.



Figure 13.2.1-3. Cumulative frequency distribution for surface silt loading on low-ADT roadways.



Figure 13.2.1-4. Cumulative frequency distribution for surface silt loading on high-ADT roadways, based on samples during first half of the calendar year.



Figure 13.2.1-5. Cumulative frequency distribution for surface silt loading on high-ADT roadways, based on samples during second half of the calendar year.



Figure 13.2.1-6. Cumulative frequency distribution for surface silt loading on low-ADT roadways, based on samples during first half of the calendar year.


Figure 13.2.1-7. Cumulative frequency distribution for surface silt loading on low-ADT roadways, based on samples during second half of the calendar year.

Table 13.2.1-3. NONINDUSTRIAL PAVED ROAD SAMPLING DATA^a

ST	City	Sampling Location, Street, Road Name	Class ^a	Date	ADT ^a	Silt Loading (g/m ²)	Silt Content (%)	Total Loading (g/m ²)	Comments
MT	Billings	ND	Rural	04/78	50	0.6	18.5	3.4	
MT	Billings	Yellowstone	Residential	04/78	115	0.5	14.3	3.5	
MT	Missoula	Bancroft	Residential	04/78	4000	8.4	33.9	24.9	
MT	Butte	1st St	Residential	04/78	679	24.6	10.6	232.4	
MT	Butte	N Park Pl	Residential	04/78	60	103.7	7	1480.8	
МТ	Billings	Grand Ave	Collector	04/78	6453	1.6	19.1	13.05	2 samples, range: 1.0 - 2.2
MT	Billings	4th Ave E	Collector	04/78	3328	7.7	7.7	99.5	
MT	Missoula	6th St	Collector	04/78	3655	26	62.9	6	
MT	Butte	Harrison	Arterial	04/78	22849	1.9	5	37.3	
MT	Missoula	Highway 93	Arterial	04/78	18870	1.9	55.9	3.3	
MT	Butte	Montana	Arterial	04/78	13529	0.8	6.6	11.9	
MT	East Helena	Thurman	Residential	04/83	140	13.1	4.3	305.2	
MT	East Helena	1st St	Local	04/83	780	4	13.6	29	
MT	East Helena	Montana	Collector	04/83	2700	8.2	9.4	86.6	
MT	East Helena	Main St	Collector	04/83	1360	4.7	8.4	55.3	
МТ	Libby	6th	Local	03/88	1310	ND	14.8	ND	
MT	Libby	5th	Local	03/88	331	ND	16.5	ND	
MT	Libby	Champion Int So gate	Collector	03/88	800	ND	27.5	ND	
MT	Libby	Mineral Ave	Collector	03/88	5900	7	16	43.5	

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			Sampling Location,	Classi	Data		Silt Loading	Silt Content	Total Loading	Comments
	ST	City	Street, Koad Name	Class	Date	ADI	(g/m)	(70)	(g/m)	Comments
	MT	Libby	Main Ave btwn 6th &	Collector	03/88	536	61	20.4	299.2	
	MT	Libby	California	Collector	03/88	4500	ND	12.1	ND	
	MT	Libby	US 2	Arterial	03/88	10850	ND	12.3	ND	
	MT	Butte	Garfield Ave	Residential	04/88	562	2.1	10.9	19.3	
	MT	Butte	Continental Dr	Arterial	04/88	5272	0.9	10.1	8.8	
Į	MT	Butte	Garfield Ave	Residential	06/89	562	1	8.7	11.2	
	MT	Butte	So Park Ave	Residential	06/89	60	2.8	10.9	25.5	
	MT	Butte	Continental Dr	Arterial	06/89	5272	7.2	3.6	197.6	
	MT	East Helena	Morton St	Local	08/89	250	1.7	6.8	24.6	
	MT	East Helena	Main St	Collector	08/89	2316	0.7	4.1	17	
	MT	East Helena	US 12	Arterial	08/89	7900	2.1	12.5	16.5	
	MT	Columbia Falls	7th St	Residential	03/90	390	ND	9.5	ND	
	MT	Columbia Falls	4th St	Residential	03/90	400	18.8	14.3	131.5	
	MT	Columbia Falls	3rd Ave	Residential	03/90	50	ND	14.3	ND	
	MT	Columbia Falls	4th Ave	Residential	03/90	1720	ND	5.4	ND	
	MT	Columbia Falls	CF Forest	Local	03/90	240	ND	16.3	ND	
	MT	Columbia Falls	12th Ave	Collector	03/90	1510	ND	8.8	ND	
	MT	Columbia Falls	3rd St	Collector	03/90	1945	ND	7	ND	
	мт	Columbia Falls	Nucleus	Collector	03/90	4730	15.4	10	153.9	

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ST	City	Sampling Location, Street, Road Name	Class ^a	Date	ADT ^a	Silt Loading (g/m ²)	Silt Content (%)	Total Loading (g/m ²)	Comments
MT	Columbia Falls	Plum Creek	Collector	03/90	316	ND	6.2	ND	
MT	Columbia Falls	6th Ave	Collector	03/90	1764	ND	4.2	ND	
MT	Columbia Falls	US 2	Arterial	03/90	13110	2.7	18.7	14.6	
MT	East Helena	Morton	Residential	07/90	250	1.6	17	9.3	
MT	East Helena	Main St	Collector	07/90	2316	5.6	10.6	52.5	
MT	East Helena	US 12	Arterial	07/90	7900	3.2	15.4	20.9	
MT	Columbia Falls	4th Ave	Local	08/90	400	1.5	4	37.7	
MT	Libby	Main Ave 4th &	Collector	08/90	530	2.4	17.9	13.2	
MT	Columbia Falls	Nucleus	Collector	08/90	5730	0.8	5.3	16	
MT	Columbia Falls	US 2	Arterial	08/90	13039	0.2	7	2.9	×
MT	East Helena	Morton	Local	10/90	250	3.4	10.2	33.6	
MT	East Helena	Main	Collector	10/90	2316	4.5	5.6	81.3	
MT	East Helena	US 12	Arterial	10/90	7900	0.6	13.9	4.3	
MT	Columbia Falls	Nucleus	Collector	11/06/90	5670	5.2	13.5	38	
MT	Columbia Falls	US 2	Arterial	11/06/90	15890	1.7	24.1	7.2	
МТ	Libby	US 2	Arteria1	12/08/90	10000	21.5	9.6	223.9	
MT	Libby	Main Ave 4th &	Collector	12/09/90	530	13.6	27.1	50.3	
MT	Butte	Texas	Collector	12/13/90	3070	1	15.4	6.4	
MT	East Helena	King	Local	01/91	75	1	3.4	30.6	

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EMISSION FACTORS

Silt Silt Total Loading Loading Sampling Location, Content (g/m^2) (g/m^2) **ADT**^a Comments Street, Road Name Class^a Date (%) ST City 12 1.8 666.5 East Helena Local 01/91 425 Prickly Pear MT 01/91 250 14.1 3.5 402.3 East Helena Morton Local MT 01/91 2316 36.7 12.1 303.4 East Helena Main St Collector MT 01/91 7900 0.8 14 5.6 East Helena US 12 Arterial MT 01/23/91 920 9.2 9.9 93 Local Thompson Falls Preston MT 01/23/91 5000 33.3 27.2 122.2 Highway 200 Collector Thompson Falls MT 02/91 150 21.6 7.1 304.7 Seaver Park Rd Local East Helena MT 02/91 2140 19.2 9 213.4 East Helena New Lake Helena Dr Collector MT 850 74.4 7.7 966.8 02/91 East Helena Porter Collector MT 33.3 178.2 02/14/91 530 18.7 Main Ave 4th & Collector MT Libby 69.3 330.3 US 2 02/17/91 10000 21 Arterial Libby MT 3070 1.2 10.9 02/21/91 11 Collector Butte Texas MT 2.9 7.9 02/21/91 22849 36.6 Arterial Harrison MT Butte 02/24/91 30.5 24.8 2653 122.9 Kalispell 3rd btwn Main & 1st Collector MT 02/24/91 14730 17.4 20.4 85.2 Arterial Main MT Kalispell 35.7 17.9 199.6 920 02/25/91 Thompson Falls Local MT Preston 02/25/91 5000 66.8 17.8 375.3 Thompson Falls Highway 200 Collector MT 03/91 15.4 248.3 21900 6.2 MT Helena Montana Arterial

ST	City	Sampling Location, Street, Road Name	Class ^a	Date	ADT ^a	Silt Loading (g/m ²)	Silt Content (%)	Total Loading (g/m ²)	Comments
MT	Kalispell	3rd btwn Main & 1st	Collector	03/09/91	2653	39.1	29.1	134.5	
MT	Columbia Falls	Nucleus	Collector	03/91	5670	30.1	17	174.6	2 samples, range: 0.8 - 0.8
MT	Kalispell	Main	Arterial	03/09/91	14730	17.6	24.7	71.4	
MT	Thompson Falls	Preston	Local	03/91	920	4.4	8.3	51	2 samples, range: 2.8 - 5.9
MT	Thompson Falls	Highway 200	Collector	03/91	5000	4.3	15.5	28.9	2 samples, range: 1.0 - 7.5
MT	Libby	Main Ave 4th &	Collector	03/91	530	14.8	33.1	44.9	2 samples, range: 13.5 - 16.1
MT	Libby	US 2	Arterial	03/91	11963	20	19.5	111.9	3 samples, range: 11.4 - 32.4
MT	East Helena	Morton	Local	04/91	250	4.3	8.8	48.7	
MT	East Helena	US 12	Arterial	04/91	7900	0.5	8.7	5.7	
MT	Thompson Falls	Preston	Local	04/91	920	1.2	15.7	6.3	4 samples, range: 0.3 - 4.0
MT	Thompson Falls	Highway 200	Collector	04/04/91	5000	2	13.4	14.7	2 samples, range: 1.1 - 2.2
MT	Libby	Main Ave 4th &	Collector	04/91	530	3.5	44	7.8	2 samples, range: 2.5 - 4.4
МТ	Libby	US 2	Arterial	04/91	12945	11.8	20.5	57.2	4 samples, range: 1.2 - 22.9
MT	Kalispell	3rd btwn Main & 1st	Collector	04/14/91	2653	15.1	37.1	40.9	
MT	Columbia Falls	Nucleus	Collector	04/91	5670	9	19.8	47.6	
MT	Kalispell	Main	Arterial	04/14/91	14730	13	44.5	29.4	
MT	Columbia Falls	Nucleus	Collector	05/91	5670	2.4	17.5	15.9	4 samples, range: 1.3 - 3.8
MT	Columbia Falls	US 2	Arterial	05/91	14712	5.5	20.7	24.8	5 samples, range: 1.5 - 14.2
MT	Libby	Main Ave 4th &	Collector	05/19/91	530	1.7	31	5.7	

		Sempling Location				Silt Loading	Silt Content	Total Loading	
ST	City	Street, Road Name	Class ^a	Date	ADT ^a	(g/m ²)	(%)	(g/m ²)	Comments
MT	Libby	Main Ave 4th &	Collector	06/27/91	530	1.7	24.3	7.1	
MT	Libby	US 2	Arterial	06/27/91	10000	3.8	12.6	30.6	
MT	East Helena	Morton	Local	07/91	250	1.7	11.4	15.3	
MT	East Helena	Main	Collector	07/91	2316	8.8	11	79.7	
MT	Thompson Falls	Preston	Local	07/09/91	920	10.9	11	98.7	
MT	Thompson Falls	Highway 200	Collector	07/09/91	5000	2.1	8.1	25.9	
MT	Helena	Montana	Arterial	07/17/91	21900	0.9	4.7	19.4	
MT	Butte	Texas	Collector	07/26/91	3070	2.5	28.2	8.9	
MT	Butte	Harrison	Arterial	07/26/91	22849	1.6	28.2	5.8	
MT	Kalispell	3rd btwn Main & 1st	Collector	08/03/91	2653	5.8	23	25.3	
MT	Kalispell	Main	Arterial	08/03/91	14730	4	21	19.3	
MT	Columbia Falls	US 2	Arterial	08/11/91	15890	0.1	5.6	2.3	
MT	Missoula	Russel btwn 4th & 5th	Road	08/30/91	5270	1.6	8.3	19.3	
MT	East Helena	US 12	Arterial	08/30/91	7900	7	20.5	34.3	
MT	Butte	Texas	Collector	10/03/91	3070	1	17.7	5.4	
MT	Butte	Harrison	Arterial	10/03/91	22849	2.1	23.1	9.1	
MT	Kalispell	3rd btwn Main & 1st	Collector	10/06/91	2653	10	31.3	31.9	
MT	Kalispell	Main	Arterial	10/06/91	14730	4.3	27.7	15.7	
MT	East Helena	Morton	Local	10/16/91	250	1.8	31	5.9	

ST	City	Sampling Location, Street, Road Name	Class ^a	Date	ADTª	Silt Loading (g/m ²)	Silt Content (%)	Total Loading (g/m ²)	Comments
MT	East Helena	Main St	Collector	10/16/91	2316	1.6	20.5	7.7	
MT	East Helena	US 12	Arterial	10/16/91	7900	1	6.7	14.9	
MT	Columbia Falls	Nucleus	Collector	10/20/91	5670	1.9	13.9	13.3	
МТ	Columbia Falls	US 2	Arterial	10/20/91	15890	1.2	11.3	10.2	
MT	Kalispell	3rd btwn Main & 1st	Collector	11/06/91	2653	2.2	12.3	17.8	
MT	Kalispell	Main	Arterial	11/28/91	14730	2.7	8.6	30.8	
MT	Thompson Falls	Preston	Local	12/17/91	920	4	18.1	22.5	
MT	Thompson Falls	Highway 200	Collector	12/17/91	5000	1.5	13.2	11.6	
MT	Butte	Texas	Collector	02/02/92	3070	19.1	11.6	164.5	
MT	Butte	Harrison	Arterial	02/02/92	22849	8.3	12	69.3	
MT	East Helena	Morton	Local	02/03/92	250	78.3	9.5	824.7	
MT	Libby	W 4th St	Local	02/03/92	350	36.3	56.3	64.5	
MT	Libby	Main Ave 4th &	Collector	02/03/92	530	10.7	49.9	21.4	
MT	East Helena	Main St	Collector	02/03/92	2316	57.9	14.8	391	
MT	Columbia Falls	Nucleus	Collector	02/03/92	5670	29.2	20.1	145.4	
MT	Columbia Falls	US 2	Arterial	02/92	12945	51.3	32.2	143.1	2 samples, range: 13.0 - 89.5
MT	East Helena	US 12	Arterial	02/03/92	7900	2.9	14.3	20.7	
MT	Thompson Falls	Preston	Local	02/22/92	920	0.5	18	2.6	
MT	Thompson Falls	Highway 200	Collector	02/22/92	5000	1.2	14.6	8.1	

		and the second							
ST	City	Sampling Location, Street, Road Name	Class ^a	Date	ADT ^a	Silt Loading (g/m ²)	Silt Content (%)	Total Loading (g/m ²)	Comments
MT	Kalispell	3rd btwn Main & 1st	Collector	03/15/92	2653	81.1	37.3	217.3	
MT	Kalispell	Main	Arterial	03/15/92	14730	16.5	32.1	51.3	
МТ	Thompson Falls	Preston	Local	04/92	920	0.43	14.9	3.2	
MT	Thompson Falls	Highway 200	Collector	04/92	5000	0.8	18.2	4.7	3 samples, range: 0.4 - 1.0
МТ	Kalispell	3rd btwn 2nd & 3rd	Local	04/26/92	450	20.9	45.8	45.5	
МТ	Kalispell	3rd btwn Main & 1st	Collector	04/26/92	2653	19.2	50.9	37.7	
MT	Kalispell	Main	Arterial	04/26/92	14730	10.7	33.5	32.1	
МТ	Kalispell	3rd btwn 2nd & 3rd	Local	05/92	450	8.3	35.6	23.5	3 samples, range: 6.6 - 10.3
MT	Kalispell	3rd btwn Main & 1st	Collector	05/92	2653	8.5	32.4	25.8	3 samples, range: 6.3 - 11.4
MT	Kalispell	Main	Arterial	05/92	14730	5.1	23.6	21.7	3 samples, range: 3.8 - 5.9
MT	Libby	W 4th St	Local	05/11/92	350	13.4	56.5	23.7	
MT	Libby	Main Ave 4th &	Collector	05/11/92	530	5.6	58.9	9.4	
MT	Libby	US 2	Arterial	05/92	12945	10.4	25.6	29.4	
MT	East Helena	Morton	Local	05/15/92	250	6.9	6.7	103	
MT	East Helena	Main St	Collector	05/15/92	2316	6.4	10.2	62.8	
MT	East Helena	US 12	Arterial	05/15/92	7900	1.2	6.9	17	
MT	Columbia Falls	Nucleus	Collector	05/25/92	5670	1	21.7	4.5	
MT	Missoula	Inez btwn 4th & 5th	Local	06/04/92	500	1	17.4	5.6	

13.2.1-20

Table 13.2.1-3 (cont.).

ST	City	Sampling Location, Street, Road Name	Class ^a	Date	ADTª	Silt Loading (g/m ²)	Silt Content (%)	Total Loading (g/m ²)	Comments
MT	Missoula	Russel btwn 3rd & 4th	Collector	06/04/92	5270	15.2	14	108.4	
MT	Missoula	3rd btwn Prince & In	Arterial	06/04/92	12000	2	13.1	15.7	
CO	Denver	E. Colfax	Princ. Arterial ^b	03/89	1994 ^c	0.21	2	19.9	4 samples, range: 0.04 - 0.47
co	Denver	E. Colfax	Princ. Arterial ^b	04/89	2228°	0.73	1.7	106.7	18 samples, range: 0.08 - 1.76
со	Denver	York St	Princ. Arterial ^b	04/89	780 ^c	0.86	1.2	74.8	2 samples, range: 0.83 - 0.89
со	Denver	E. Belleview	Princ. Arterial ^b	04/89	ND	0.07	4.2	2	3 samples, range: 0.03 - 0.09
со	Denver	I-225	Expressway ^b	04/89	4731°	0.02	3.6	0.4	3 samples, range: 0.01 - 0.02
со	Denver	W. Evans	Princ. Arterial ^b	05/89	1905°	0.76	1.9	74	11 samples, range: 0.03 - 2.24
со	Denver	W. Evans	Princ. Arterial ^b	06/89	1655°	0.71	1.2	66.1	12 samples, range: 0.07 - 3.34
со	Denver	E. Louisiana	Minor Arterial ^b	06/89	515°	0.14	4.66	3.5	5 samples, range: 0.08 - 0.24
со	Denver	E. Louisiana	Minor Arterial ^b	01/90	ND	1.44 ^d	ND	ND	6 samples, range: 0.12 - 2.8
со	Denver	E. Jewell Ave	Collector ^b	01/24/90	ND	2.24 ^d	ND	ND	
со	Denver	State Highway 36	Expressway ^b	01/30/90	ND	0.56 ^d	ND	ND	2 samples, range: 0.56 - 0.56

Table 13.2.1-3 (cont.).

ST	City	Sampling Location, Street, Road Name	Class ^a	Date	ADT ^a	Silt Loading (g/m ²)	Silt Content (%)	Total Loading (g/m ²)	Comments
со	Denver	State Highway 36	Expressway ^b	02/01/90	ND	1.92 ^d	ND	ND	4 samples, range: 1.92 - 1.92
со	Denver	W. Evans Ave	Princ. Arterial ^b	02/03/90	ND	1.64 ^d	ND	ND	2 samples, range: 1.64 - 1.64
со	Denver	E. Mexico St	Local ^b	02/07/90	ND	2.58 ^d	ND	ND	3 samples, range: 2.58 - 2.58
со	Denver	E. Colfax Ave	Princ. Arterial ^b	02/90	ND	0.09 ^d	ND	ND	16 samples, range: 0.02 - 0.17
со	Denver	State Highway 36	Expressway ^b	03/90	ND	ND	ND	ND	7 samples
со	Denver	E. Louisiana Ave	Minor Arterial ^b	03/10/90	ND	ND	ND	ND	3 samples
со	Denver	W. Evans Ave	Princ. Arterial ^b	03/90	ND	1.27 ^d	ND	ND	5 samples, range: 0.07 - 3.38
со	Denver	W. Colfax Ave	Princ. Arterial ^b	03/90	ND	0.41 ^d	ND	ND	21 samples, range: 0.04 - 2.61
со	Denver	Parker Rd	Local ^b	04/90	ND	0.05 ^d	ND	ND	6 samples, range: 0.01 - 0.11
со	Denver	W. Byron Pl	Princ. Arterial ^b	04/90	ND	0.3 ^d	ND	ND	6 samples, range: 0.21 - 0.35
со	Denver	E. Colfax Ave	Princ. Arterial ^b	04/18/90	ND	0.21 ^d	ND	ND	
UT	Salt Lake County	700 East	Arterial	e	42340	0.137	11.5	1.187	4 samples, range: 0.107 - 0.162

		·····			· · · · · ·		· · · · · · · · · · · · · · · · · · ·		
ST	City	Sampling Location, Street, Road Name	Class ^a	Date	ADT ^a	Silt Loading (g/m ²)	Silt Content (%)	Total Loading (g/m ²)	Comments
UT	Salt Lake County	State St	Collector	e	27140	0.288	17	1.692	4 samples, range: 0.212 - 0.357
UT	Salt Lake County	I-80	Freeway	e	77040	0.023	21.4	0.1	5 samples, range: 0.011 - 0.034
UT	Salt Lake County	I-15	Freeway	e	146180	0.096	23.5	0.419	6 samples, range: 0.078 - 0.126
UT	Salt Lake County	400 East	Local	e	5000	1.967	4.07	46.043	14 samples, range: 0.177 - 5.772
NV	Las Vegas	Lake Mead	Major	07/15/87	ND	0.81	12.4	6.51	
NV	Las Vegas	Perliter	Local	07/15/87	ND	2.23	31.2	7.14	
NV	Las Vegas	Bruce	Collector	07/15/87	ND	1.64	26.1	6.3	
NV	Las Vegas	Stewart	Major	09/29/87	ND	0.38	24	1.63	3 samples, range: 0.24 - 0.46
NV	Las Vegas	Ambler	Local	09/29/87	ND	1.38	23	6.32	3 samples, range: 0.64 - 2.00
NV	Las Vegas	28th St	Collector	09/29/87	ND	0.52	15.8	3.4	3 samples, range: 0.51 - 0.54
NV	Las Vegas	Lake Mead	Major	10/07/87	ND	0.19	14.9	1.26	2 samples, range: 0.17 - 0.20
NV	Las Vegas	Perliter	Local	10/07/87	ND	1.5	31.9	4.76	2 samples, range: 1.48 - 1.52
NV	Las Vegas	Bruce	Collector	10/07/87	ND	0.9	24.1	3.74	2 samples, range: 0.76 - 1.03
AZ	Phoenix	Broadway	Arterial	_f	ND	0.127	12.2	1.071	
AZ	Phoenix	South Central	Arterial	f	ND	0.085	5	1.726	
AZ	Phoenix	Indian School & 28th	Arterial	f	ND	0.035	3.1	1.021	

13.2.1-24

Silt Silt Total Loading Loading Content Sampling Location, **ADT**^a (g/m^2) (g/m^2) ST Street, Road Name Class^a (%) Comments City Date _f 3.9 1.049 ΑZ 43rd & Vista Arterial ND 0.042 Glendale __f 8.2 0.099 1.183 59th & Peoria ND Arterial ΑZ Glendale __f ND 0.099 8.9 1.085 Mesa Drive Arterial ΑZ Mesa _f E. McKellips & Olive ND 0.014 17 0.092 Arterial ΑZ Mesa ___f 17th & Highland ND 0.028 13.4 0.232 Collector ΑZ Phoenix __f ND 0.07 11.8 0.627 ΑZ Mesa 3rd & Miller Collector __f ND 0.528 11.1 4.79 Avalon & 25th Collector ΑZ Phoenix __f ND 0.282 6.4 4.367 ΑZ Phoenix Apache Collector __f ND 0.035 1.479 2.3 Phoenix N. 28th St & E. Collector AZ Glenrosa __f 6.417 19.961 ND 1.282 Pima County 6th Ave Collector ΑZ ___f 8.117 4.937 ND 0.401 Pima County Speedway Blvd Arterial ΑZ __f 0.028 ND 16.529 0.176 Pima County 22nd St Arterial ΑZ __f 0.014 5.506 0.197 Pima County Amklam Rd Collector ND ΑZ __f ND 0.113 3,509 3.268 Pima County Fort Lowel Rd Arterial AZ _f 0.014 0.725 Oracle Rd Arterial ND 1.556 Pima County ΑZ _f 0.021 0.127 Pima County Inn Rd ND 18.756 ΑZ Arterial ___f 21.989 0.725 Orange Grove ND 0.162 Pima County Arterial ΑZ __f 3.975 2.571 La Canada ND 0.106 Arterial ΑZ **Pima County**

Table 13.2.1-3 (cont.).

Table 13.2.1-3 (cont.).

ST	City	Sampling Location, Street, Road Name	Class ^a	Date	ADT ^a	Silt Loading (g/m ²)	Silt Content (%)	Total Loading (g/m ²)	Comments
KS	Kansas City	7th	Arterial	02/80	ND	0.29	6.8	4.2	3 samples, range: 0.15 - 0.46
мо	Kansas City	Volker	Arterial	02/80	ND	0.67	20.1	3.5	3 samples, range: 0.43 -1.00
мо	Kansas City	Rockhill	Arterial	02/80	ND	0.68	21.7	3.3	
KS	Tonganoxie	4th	Collector	03/80	ND	2.5	14.5	17.1	
KS	Kansas City	7th	Arterial	03/80	ND	0.29	12.2	2.4	
мо	St. Louis	I-44	Expressway	05/80	ND	0.02	ND	ND	4 samples
мо	St. Louis	Kingshighway	Collector	05/80	ND	0.08	10.9	0.7	3 samples, range: 0.05 - 0.11
L	Granite City	24th	Arterial	05/80	ND	0.78	6.4	12.3	2 samples, range: 0.7 - 0.83
IL	Granite City	Benton	Collector	05/80	ND	0.93	8.6	10.8	
MN	Duluth	US 53 (northbound lanes)	Highway	03/19/92	5000	0.23	28	1.94	8 samples, range: 0.04 - 0.77
MN	Duluth	US 53 (southbound lanes)	Highway	02/26/92	5000	0.24	13.4	2.3	5 samples, range: 0.05 - 0.37

^a References 7,13-20. Classifications and values as given in reference, except as noted. ADT = average daily traffic. ND = no data.

^b Reference 16.

 ^c Value given is the hourly traffic rate observed during testing. ADT values not reported.
 ^d Samples are said to wet sieved. Wet sieving results are not directly comparable to those for the dry sieving described in AP-42 Appendix C.2.

^e No specific date given for sampling. Samples are said to be "post storm".
 ^f No specific date given for sampling.

Miscellaneous Sources

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13.2.2 Unpaved Roads

13.2.2.1 General

Dust plumes trailing behind vehicles traveling on unpaved roads are a familiar sight in rural areas of the United States. When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

13.2.2.2 Emissions Calculation And Correction Parameters

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Field investigations also have shown that emissions depend on correction parameters (average vehicle speed, average vehicle weight, average number of wheels per vehicle, road surface texture, and road surface moisture) that characterize the condition of a particular road and the associated vehicle traffic.¹⁻⁴

Dust emissions from unpaved roads have been found to vary in direct proportion to the fraction of silt (particles smaller than 75 micrometers $[\mu m]$ in diameter) in the road surface materials.¹ The silt fraction is determined by measuring the proportion of loose dry surface dust that passes a 200-mesh screen, using the ASTM-C-136 method. Table 13.2.2-1 summarizes measured silt values for industrial and rural unpaved roads.

Since the silt content of a rural dirt road will vary with location, it should be measured for use in projecting emissions. As a conservative approximation, the silt content of the parent soil in the area can be used. Tests, however, show that road silt content is normally lower than in the surrounding parent soil, because the fines are continually removed by the vehicle traffic, leaving a higher percentage of coarse particles.

Unpaved roads have a hard, generally nonporous surface that usually dries quickly after a rainfall. The temporary reduction in emissions caused by precipitation may be accounted for by not considering emissions on "wet" days (more than 0.254 millimeters [mm] [0.01 inches (in.)] of precipitation).

The following empirical expression may be used to estimate the quantity of size-specific particulate emissions from an unpaved road, per vehicle kilometer traveled (VKT) or vehicle mile traveled (VMT):

$$E = k(1.7) \quad \left(\frac{s}{12}\right) \quad \left(\frac{s}{48}\right) \quad \left(\frac{W}{2.7}\right)^{0.7} \quad \left(\frac{w}{4}\right)^{0.5} \quad \left(\frac{365-p}{365}\right) \quad (kilograms [kg]/VKT)$$

$$(1)$$

$$E = k(5.9) \quad \left(\frac{s}{12}\right) \quad \left(\frac{S}{30}\right) \quad \left(\frac{W}{3}\right)^{0.7} \quad \left(\frac{w}{4}\right)^{0.5} \quad \left(\frac{365-p}{365}\right) \quad (pounds [lb]/VMT)$$

Miscellaneous Sources

13.2.2-1

	Road Use Or	Plant	No. Of	Silt Conte	ent (%)
Industry	Surface Material	Sites	Samples	Range	Mean
Copper smelting	Plant road	1	3	16 - 19	17
Iron and steel production	Plant road	19	135	0.2 - 19	6.0
Sand and gravel processing	Plant road	1	3	4.1 - 6.0	4.8
Stone quarrying and processing	Plant road	2	10	2.4 - 16	10
	Haul road	1	10	5.0 - 15	9.6
Taconite mining and processing	Service road Haul road	1	8 12	2.4 - 7.1 3.9 - 9.7	4.3 5.8
Western surface coal					
mining	Haul road	3	21	2.8 - 18	8.4
	Access road	2	2	4.9 - 5.3	5.1
	Scraper route	3	10	7.2 - 25	17
	Haul road (freshly graded)	2	5	18 - 29	24
Rural roads	Gravel/crushed limestone	3	9	5.0 - 13	8.9
	Dirt	7	32	1.6 - 68	12
Municipal roads	Unspecified	3	26	0.4 - 13	5.7
Municipal solid waste landfills	Disposal routes	4	20	2.2 - 21	6.4

Table 13.2.2-1. TYPICAL SILT CONTENT VALUES OF SURFACE MATERIAL ON INDUSTRIAL AND RURAL UNPAVED ROADS^a

^a References 1,5-16.

where:

- E = emission factor
- k = particle size multiplier (dimensionless)
- s = silt content of road surface material (%)
- S = mean vehicle speed, kilometers per hour (km/hr) (miles per hour [mph])
- W = mean vehicle weight, megagrams (Mg) (ton)
- w = mean number of wheels
- p = number of days with at least 0.254 mm (0.01 in.) of precipitation per year (see discussion below about the effect of precipitation.)

EMISSION FACTORS

The particle size multiplier in the equation, k, varies with aerodynamic particle size range as follows:

Aerodynamic Particle Size Multiplier (k) For Equation 1							
\leq 30 μ m ^a	≤30 µm	≤15 μm	≤10 µm	≤5 µm	≤2.5 µm		
1.0	0.80	0.50	0.36	0.20	0.095		

^a Stokes diameter.

It is important to note that Equation 1 calls for the average speed, weight, and number of wheels of all vehicles traveling the road. For example, if 98 percent of traffic on the road are 4-wheeled cars and trucks while the remaining 2 percent consists of 18-wheeled trucks, then the mean number of wheels "w" is 4.3. More specifically, Equation 1 is *not* intended to be used to calculate a separate emission factor for each vehicle class. Instead, only one emission factor should be calculated that represents the "fleet" average of all vehicles traveling the road.

The number of wet days per year, p, for the geographical area of interest should be determined from local climatic data. Figure 13.2.2-1 gives the geographical distribution of the mean annual number of wet days per year in the United States.¹⁷ The equation is rated "A" for dry conditions (p = 0) and "B" for annual or seasonal conditions (p > 0). The lower rating is applied because extrapolation to seasonal or annual conditions assumes that emissions occur at the estimated rate on days without measurable precipitation and, conversely, are absent on days with measurable precipitation. Clearly, natural mitigation depends not only on how much precipitation falls, but also on other factors affecting the evaporation rate, such as ambient air temperature, wind speed, and humidity. Persons in dry, arid portions of the country may wish to base p (the number of wet days) on a greater amount of precipitation than 0.254 mm (0.01 in.). In addition, Reference 18 contains procedures to estimate the emission reduction achieved by the application of water to an unpaved road surface.

The equation retains the assigned quality rating, if applied within the ranges of source conditions that were tested in developing the equation, as follows:

Ranges Of Source Conditions For Equation							
Road Silt Content	Mean Vehi	cle Weight	Mean Vel	Moon No			
(wt %)	Mg	ton	km/hr	mph	Of Wheels		
4.3 - 20	2.7 - 142	3 - 157	21 - 64	13 - 40	4 - 13		

Moreover, to retain the quality rating of the equation when addressing a specific unpaved road, it is necessary that reliable correction parameter values be determined for the road in question. The field and laboratory procedures for determining road surface silt content are given in AP-42 Appendices C.1 and C.2. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean values from Table 13.2.2-1 may be used, but the quality rating of the equation is reduced by 1 letter.

For calculating annual average emissions, the equation is to be multiplied by annual vehicle distance traveled (VDT). Annual average values for each of the correction parameters are to be

Miscellaneous Sources





Figure 13.2.2-1. Mean number of days with 0.01 inch or more of precipitation in United States.

substituted for the equation. Worst-case emissions, corresponding to dry road conditions, may be calculated by setting p = 0 in the equation (equivalent to dropping the last term from the equation). A separate set of nonclimatic correction parameters and a higher than normal VDT value may also be justified for the worst-case average period (usually 24 hours). Similarly, in using the equation to calculate emissions for a 91-day season of the year, replace the term (365-p)/365 with the term (91-p)/91, and set p equal to the number of wet days in the 91-day period. Use appropriate seasonal values for the nonclimatic correction parameters and for VDT.

13.2.2.3 Controls¹⁸⁻²¹

Common control techniques for unpaved roads are paving, surface treating with penetration chemicals, working stabilization chemicals into the roadbed, watering, and traffic control regulations. Chemical stabilizers work either by binding the surface material or by enhancing moisture retention. Paving, as a control technique, is often not economically practical. Surface chemical treatment and watering can be accomplished at moderate to low costs, but frequent treatments are required. Traffic controls, such as speed limits and traffic volume restrictions, provide moderate emission reductions, but may be difficult to enforce. The control efficiency obtained by speed reduction can be calculated using the predictive emission factor equation given above.

The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions, relative to airborne particle size range of interest. The predictive emission factor equation for paved roads, given in Section 13.2.4, requires estimation of the silt loading on the traveled portion of the paved surface, which in turn depends on whether the pavement is periodically cleaned. Unless curbing is to be installed, the effects of vehicle excursion onto shoulders (berms) also must be taken into account in estimating control efficiency.

The control efficiencies afforded by the periodic use of road stabilization chemicals are much more difficult to estimate. The application parameters that determine control efficiency include dilution ratio, application intensity, mass of diluted chemical per road area, and application frequency. Other factors that affect the performance of chemical stabilizers include vehicle characteristics (e. g., traffic volume, average weight) and road characteristics (e. g., bearing strength).

Besides water, petroleum resin products historically have been the dust suppressants most widely used on industrial unpaved roads. Figure 13.2.2-2 presents a method to estimate average control efficiencies associated with petroleum resins applied to unpaved roads.¹⁹ Several items should be noted:

- 1. The term "ground inventory" represents the total volume (per unit area) of petroleum resin concentrate (*not solution*) applied since the start of the dust control season.
- 2. Because petroleum resin products must be periodically reapplied to unpaved roads, the use of a time-averaged control efficiency value is appropriate. Figure 13.2.2-2 presents control efficiency values averaged over 2 common application intervals, 2 weeks and 1 month. Other application intervals will require interpolation.
- 3. Note that zero efficiency is assigned until the ground inventory reaches 0.2 liter per square meter (L/m^2) (0.05 gallon per square yard [gal/yd²]).

As an example of the application of Figure 13.2.2-2, suppose that the equation was used to estimate an emission factor of 2.0 kg/VKT for PM-10 from a particular road. Also, suppose that,



Figure 13.2.2-2. Average control efficiencies over common application intervals.

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starting on May 1, the road is treated with 1 L/m^2 of a solution (1 part petroleum resin to 5 parts water) on the first of each month through September. Then, the following average controlled emission factors are found:

Period	Ground Inventory (L/m ²)	Average Control Efficiency ^a (%)	Average Controlled Emission Factor (kg/VKT)
Мау	0.17	0	2.0
June	0.33	62	0.76
July	0.50	68	0.64
August	0.67	74	0.52
September	0.83	80	0.40

^a From Figure 13.2.2-2, $\leq 10 \ \mu m$. Zero efficiency assigned if ground inventory is less than 0.2 L/m² (0.05 gal/yd²).

Newer dust suppressants are successful in controlling emissions from unpaved roads. Specific test results for those chemicals, as well as for petroleum resins and watering, are provided in References 18 through 21.

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13.2.3 Heavy Construction Operations

13.2.3.1 General

Heavy construction is a source of dust emissions that may have substantial temporary impact on local air quality. Building and road construction are 2 examples of construction activities with high emissions potential. Emissions during the construction of a building or road can be associated with land clearing, drilling and blasting, ground excavation, cut and fill operations (i.e., earth moving), and construction of a particular facility itself. Dust emissions often vary substantially from day to day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions. A large portion of the emissions results from equipment traffic over temporary roads at the construction site.

The temporary nature of construction differentiates it from other fugitive dust sources as to estimation and control of emissions. Construction consists of a series of different operations, each with its own duration and potential for dust generation. In other words, emissions from any single construction site can be expected (1) to have a definable beginning and an end and (2) to vary substantially over different phases of the construction process. This is in contrast to most other fugitive dust sources, where emissions are either relatively steady or follow a discernable annual cycle. Furthermore, there is often a need to estimate areawide construction emissions, without regard to the actual plans of any individual construction project. For these reasons, following are methods by which either areawide or site-specific emissions may be estimated.

13.2.3.2 Emissions And Correction Parameters

The quantity of dust emissions from construction operations is proportional to the area of land being worked and to the level of construction activity. By analogy to the parameter dependence observed for other similar fugitive dust sources,¹ one can expect emissions from heavy construction operations to be positively correlated with the silt content of the soil (that is, particles smaller than 75 micrometers $[\mu m]$ in diameter), as well as with the speed and weight of the average vehicle, and to be negatively correlated with the soil moisture content.

13.2.3.3 Emission Factors

Only 1 set of field studies has been performed that attempts to relate the emissions from construction directly to an emission factor.¹⁻² Based on field measurements of total suspended particulate (TSP) concentrations surrounding apartment and shopping center construction projects, the approximate emission factors for construction activity operations are:

- E = 2.69 megagrams (Mg)/hectare/month of activity
- E = 1.2 tons/acre/month of activity

These values are most useful for developing estimates of overall emissions from construction scattered throughout a geographical area. The value is most applicable to construction operations with: (1) medium activity level, (2) moderate silt contents, and (3) semiarid climate. Test data were not sufficient to derive the specific dependence of dust emissions on correction parameters. Because the above emission factor is referenced to TSP, use of this factor to estimate particulate matter (PM) no greater than 10 μ m in aerodynamic diameter (PM-10) emissions will result in conservatively high

estimates. Also, because derivation of the factor assumes that construction activity occurs 30 days per month, the above estimate is somewhat conservatively high for TSP as well.

Although the equation above represents a relatively straightforward means of preparing an areawide emission inventory, at least 2 features limit its usefulness for specific construction sites. First, the conservative nature of the emission factor may result in too high an estimate for PM-10 to be of much use for a specific site under consideration. Second, the equation provides neither information about which particular construction activities have the greatest emission potential nor guidance for developing an effective dust control plan.

For these reasons, it is strongly recommended that when emissions are to be estimated for a particular construction site, the construction process be broken down into component operations. (Note that many general contractors typically employ planning and scheduling tools, such as critical path method [CPM], that make use of different sequential operations to allocate resources.) This approach to emission estimation uses a unit or phase method to consider the more basic dust sources of vehicle travel and material handling. That is to say, the construction project is viewed as consisting of several operations, each involving traffic and material movements, and emission factors from other AP-42 sections are used to generate estimates. Table 13.2.3-1 displays the dust sources involved with construction, along with the recommended emission factors.³

In addition to the on-site activities shown in Table 13.2.3-1, substantial emissions are possible because of material tracked out from the site and deposited on adjacent paved streets. Because all traffic passing the site (i. e., not just that associated with the construction) can resuspend the deposited material, this "secondary" source of emissions may be far more important than all the dust sources actually within the construction site. Furthermore, this secondary source will be present during all construction operations. Persons developing construction site emission estimates must consider the potential for increased adjacent emissions from off-site paved roadways (see Section 13.2.1, "Paved Roads"). High wind events also can lead to emissions from cleared land and material stockpiles. Section 13.2.5, "Industrial Wind Erosion", presents an estimation methodology that can be used for such sources at construction sites.

13.2.3.4 Control Measures⁴

Because of the relatively short-term nature of construction activities, some control measures are more cost effective than others. Wet suppression and wind speed reduction are 2 common methods used to control open dust sources at construction sites, because a source of water and material for wind barriers tend to be readily available on a construction site. However, several other forms of dust control are available.

Table 13.2.3-2 displays each of the preferred control measures, by dust source.³⁻⁴ Because most of the controls listed in the table modify independent variables in the emission factor models, the effectiveness can be calculated by comparing controlled and uncontrolled emission estimates from Table 13.2.3-1. Additional guidance on controls is provided in the AP-42 sections from which the recommended emission factors were taken, as well as in other documents, such as Reference 4.

Table 13.2.3-1. RECOMMENDED EMISSION FACTORS FOR CONSTRUCTION OPERATIONS^a

Construction Phase	Dust-generating Activities	Recommended Emission Factor	Comments	Rating Adjustment ^b
I. Demolition and debris removal	 Demolition of buildings or other (natural) obstacles such as trees, boulders, etc. a. Mechanical dismemberment 			-
	("headache ball") of existing structures h. Implosion of existing	NA		
	structures	NA		
	c. Drilling and blasting of soil	Drilling factor in Table 11.9-4		-1
	•	Blasting factor NA	Blasting factor in Tables 11.9-1 and 11.9-2 not considered appropriate for	
	d. General land clearing	Dozer equation (overburden) in Tables 11.9-1 and 11.9-2	general construction activities	NA -1/-2°
	2. Loading of debris into trucks	Material handling factor in Section 13.2.2		-0/-1°
	3. Truck transport of debris	Unpaved road emission factor in Section 13.2.2, or paved road emission factor in Section 13.2.1		-0/-1°
	4. Truck unloading of debris	Material handling factor in Section 13.2.2	May occur offsite	-0/-1°

Construction Phase		Dust-generating Activities	Recommended Emission Factor	Comments	Rating Adjustment ^b
II. Site Preparation (earth moving)	1.	Bulldozing	Dozer equation (overburden) in Tables 11.9-1 and 11.9-2		-1/-2°
	2.	Scrapers unloading topsoil	Scraper unloading factor in Table 11.9-4		-1
	3.	Scrapers in travel	Scraper (travel mode) expression in Tables 11.9-1 and 11.9-2		-0/-1°
	4.	Scrapers removing topsoil	5.7 kg/vehicle kilometer traveled (VKT) (20.2 lb/vehicle mile traveled [VMT])		Eď
	5.	Loading of excavated material into trucks	Material handling factor in Section 13.2.2		-0/-1°
	6.	Truck dumping of fill material, road base, or other materials	Material handling factor in Section 13.2.2	May occur offsite	-0/-1°
	7.	Compacting	Dozer equation in Tables 11.9-1 and 11.9-2	Emission factor downgraded because of differences in operating equipment	-1/-2°
	8.	Motor grading	Grading equation in Tables 11.9-1 and 11.9-2		-1/-2°

13.2.3-4

Construction Phase	Dust-generating Activities	Recommended Emission Factor	Comments	Rating Adjustment ^b
III. General Construction	1. Vehicular traffic	Unpaved road emission factor in Section 13.2.2, or paved road emission factor in Section 13.2.1		-0/-1° -0/-1°
	2. Portable plants			
	a. Crushing	Factors for similar material/operations in Chapter 11 of this document		-1/-2°
	b. Screening	Factors for similar material/operations in Chapter 11 of this document		-1/-2°
	c. Material transfers	Material handling factor in Section 13.2.2		-0/-1°
	3. Other operations	Factors for similar material/operations in Chapter 11 of this document		—

^a NA = not applicable.

^b Refers to how many additional letters the emission factor should be downrated (beyond the guidance given in the other sections of AP-42) for application to construction activities. For example, "-2" means that an A-rated factor should be considered of C quality in estimating construction emissions. All emission factors assumed to have site-specific input values; otherwise, additional downgrading of one letter should be employed. Note that no rating can be lower than E.

^c First value for cases with independent variables within range given in AP-42 section; second value for cases with at least 1 variable outside the range.

^d Rating for emission factor given. Reference 5.

^e In the event that individual operations cannot be identified, one may very conservatively overestimate PM-10 emissions by using Equation 1.

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Table 13.2.3-2.CONTROL OPTIONS FOR GENERAL CONSTRUCTION
OPEN SOURCES OF PM-10

Emission Source	Recommended Control Method(s)
Debris handling	Wind speed reduction Wet suppression ^a
Truck transport ^b	Wet suppression Paving Chemical stabilization ^c
Bulldozers	Wet suppression ^d
Pan scrapers	Wet suppression of travel routes
Cut/fill material handling	Wind speed reduction Wet suppression
Cut/fill haulage	Wet suppression Paving Chemical stabilization
General construction	Wind speed reduction Wet suppression Early paving of permanent roads

^a Dust control plans should contain precautions against watering programs that confound trackout problems.

- ^b Loads could be covered to avoid loss of material in transport, especially if material is transported offsite.
- ^c Chemical stabilization usually cost-effective for relatively long-term or semipermanent unpaved roads.
- ^d Excavated materials may already be moist and not require additional wetting. Furthermore, most soils are associated with an "optimum moisture" for compaction.

References For Section 13.2.3

- 1. C. Cowherd, Jr., et al., Development Of Emissions Factors For Fugitive Dust Sources, EPA-450/3-74-03, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.
- 2. G. A. Jutze, et al., Investigation Of Fugitive Dust Sources Emissions And Control, EPA-450/3-74-036a, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.
- 3. Background Documentation For AP-42 Section 11.2.4, Heavy Construction Operations, EPA Contract No. 69-D0-0123, Midwest Research Institute, Kansas City, MO, April 1993.
- 4. C. Cowherd *it al.*, Control Of Open Fugitive Dust Sources, EPA-450/3-88-008, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

5. M. A. Grelinger, et al., Gap Filling PM-10 Emission Factors For Open Area Fugitive Dust Sources, EPA-450/4-88-003, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1988.

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13.2.4 Aggregate Handling And Storage Piles

13.2.4.1 General

Inherent in operations that use minerals in aggregate form is the maintenance of outdoor storage piles. Storage piles are usually left uncovered, partially because of the need for frequent material transfer into or out of storage.

Dust emissions occur at several points in the storage cycle, such as material loading onto the pile, disturbances by strong wind currents, and loadout from the pile. The movement of trucks and loading equipment in the storage pile area is also a substantial source of dust.

13.2.4.2 Emissions And Correction Parameters

The quantity of dust emissions from aggregate storage operations varies with the volume of aggregate passing through the storage cycle. Emissions also depend on 3 parameters of the condition of a particular storage pile: age of the pile, moisture content, and proportion of aggregate fines.

When freshly processed aggregate is loaded onto a storage pile, the potential for dust emissions is at a maximum. Fines are easily disaggregated and released to the atmosphere upon exposure to air currents, either from aggregate transfer itself or from high winds. As the aggregate pile weathers, however, potential for dust emissions is greatly reduced. Moisture causes aggregation and cementation of fines to the surfaces of larger particles. Any significant rainfall soaks the interior of the pile, and then the drying process is very slow.

Silt (particles equal to or less than 75 micrometers $[\mu m]$ in diameter) content is determined by measuring the portion of dry aggregate material that passes through a 200-mesh screen, using ASTM-C-136 method.¹ Table 13.2.4-1 summarizes measured silt and moisture values for industrial aggregate materials.

13.2.4.3 Predictive Emission Factor Equations

Total dust emissions from aggregate storage piles result from several distinct source activities within the storage cycle:

- 1. Loading of aggregate onto storage piles (batch or continuous drop operations).
- 2. Equipment traffic in storage area.
- 3. Wind erosion of pile surfaces and ground areas around piles.
- 4. Loadout of aggregate for shipment or for return to the process stream (batch or continuous drop operations).

Either adding aggregate material to a storage pile or removing it usually involves dropping the material onto a receiving surface. Truck dumping on the pile or loading out from the pile to a truck with a front-end loader are examples of batch drop operations. Adding material to the pile by a conveyor stacker is an example of a continuous drop operation.

			Silt	Content (%)	Moist	ure Content	(%)
	No. Of		No. Of	_		No. Of		
Industry	Facilities	Material	Samples	Range	Mean	Samples	Range	Mean
Iron and steel production	9	Pellet ore	13	1.3 - 13	4.3	11	0.64 - 4.0	2.2
		Lump ore	9	2.8 - 19	9.5	6	1.6 - 8.0	5.4
		Coal	12	2.0 - 7.7	4.6	11	2.8 - 11	4.8
		Slag	3	3.0 - 7.3	5.3	3	0.25 - 2.0	0.92
		Flue dust	3	2.7 - 23	13	1		7
		Coke breeze	2	4.4 - 5.4	4.9	2	6.4 - 9.2	7.8
		Blended ore	1		15	1	_	6.6
		Sinter	1		0.7	0		
		Limestone	3	0.4 - 2.3	1.0	2	ND	0.2
Stone quarrying and processing	2	Crushed limestone	2	1.3 - 1.9	1.6	2	0.3 - 1.1	0.7
		Various limestone products	8	0.8 - 14	3.9	8	0.46 - 5.0	2.1
Taconite mining and processing	1	Pellets	9	2.2 - 5.4	3.4	7	0.05 - 2.0	0.9
		Tailings	2	ND	11	1	_	0.4
Western surface coal mining	4	Coal	15	3.4 - 16	6.2	7	2.8 - 20	6.9
		Overburden	15	3.8 - 15	7.5	0		_
		Exposed ground	3	5.1 - 21	15	3	0.8 - 6.4	3.4
Coal-fired power plant	1	Coal (as received)	60	0.6 - 4.8	2.2	59	2.7 - 7.4	4.5
Municipal solid waste landfills	4	Sand	1	_	2.6	1	_	7.4
	1	Slag	2	3.0 - 4.7	3.8	2	2.3 - 4.9	3.6
		Cover	5	5.0 - 16	9.0	5	8.9 - 16	12

9.2

6.0

80

12

4.5 - 7.4

78 - 81

1

2

4

1

1

2

4

1

14

10

27

11

_

8.9 - 11

26 - 29

Clay/dirt mix

Misc. fill materials

Clay

Fly ash

Table 13.2.4-1. TYPICAL SILT AND MOISTURE CONTENTS OF MATERIALS AT VARIOUS INDUSTRIES^a

13.2.4-2

EMISSION FACTORS

^a References 1-10. ND = no data.

The quantity of particulate emissions generated by either type of drop operation, per kilogram (kg) (ton) of material transferred, may be estimated, with a rating of A, using the following empirical expression:¹¹

$$E = k(0.0016) \qquad \frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \quad (kg/megagram [Mg])$$

$$(1)$$

$$E = k(0.0032) \qquad \frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \quad (pound [lb]/ton)$$

where:

E = emission factork = particle size multiplier (dimensionless)

U = mean wind speed, meters per second (m/s) (miles per hour [mph])

M = material moisture content (%)

The particle size multiplier in the equation, k, varies with aerodynamic particle size range, as follows:

Aerodynamic Particle Size Multiplier (k) For Equation 1							
< 30 µm	< 15 µm	< 10 µm	< 5 μm	< 2.5 μm			
0.74	0.48	0.35	0.20	0.11			

The equation retains the assigned quality rating if applied within the ranges of source conditions that were tested in developing the equation, as follows. Note that silt content is included, even though silt content does not appear as a correction parameter in the equation. While it is reasonable to expect that silt content and emission factors are interrelated, no significant correlation between the 2 was found during the derivation of the equation, probably because most tests with high silt contents were conducted under lower winds, and vice versa. It is recommended that estimates from the equation be reduced 1 quality rating level if the silt content used in a particular application falls outside the range given:

Ranges Of Source Conditions For Equation 1						
Silt Content	Moisture Content	Wind Speed				
(%)	(%)	m/s	mph			
0.44 - 19	0.25 - 4.8	0.6 - 6.7	1.3 - 15			

To retain the quality rating of the equation when it is applied to a specific facility, reliable correction parameters must be determined for specific sources of interest. The field and laboratory procedures for aggregate sampling are given in Reference 3. In the event that site-specific values for correction parameters cannot be obtained, the appropriate mean from Table 13.2.4-1 may be used, but the quality rating of the equation is reduced by 1 letter.

For emissions from equipment traffic (trucks, front-end loaders, dozers, etc.) traveling between or on piles, it is recommended that the equations for vehicle traffic on unpaved surfaces be used (see Section 13.2.2). For vehicle travel between storage piles, the silt value(s) for the areas among the piles (which may differ from the silt values for the stored materials) should be used.

Worst-case emissions from storage pile areas occur under dry, windy conditions. Worst-case emissions from materials-handling operations may be calculated by substituting into the equation appropriate values for aggregate material moisture content and for anticipated wind speeds during the worst case averaging period, usually 24 hours. The treatment of dry conditions for Section 13.2.2, vehicle traffic, "Unpaved Roads", follows the methodology described in that section centering on parameter p. A separate set of nonclimatic correction parameters and source extent values corresponding to higher than normal storage pile activity also may be justified for the worst-case averaging period.

13.2.4.4 Controls¹²⁻¹³

Watering and the use of chemical wetting agents are the principal means for control of aggregate storage pile emissions. Enclosure or covering of inactive piles to reduce wind erosion can also reduce emissions. Watering is useful mainly to reduce emissions from vehicle traffic in the storage pile area. Watering of the storage piles themselves typically has only a very temporary slight effect on total emissions. A much more effective technique is to apply chemical agents (such as surfactants) that permit more extensive wetting. Continuous chemical treating of material loaded onto piles, coupled with watering or treatment of roadways, can reduce total particulate emissions from aggregate storage operations by up to 90 percent.¹²

References For Section 13.2.4

- C. Cowherd, Jr., et al., Development Of Emission Factors For Fugitive Dust Sources, EPA-450/3-74-037, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.
- 2. R. Bohn, et al., Fugitive Emissions From Integrated Iron And Steel Plants, EPA-600/2-78-050, U. S. Environmental Protection Agency, Cincinnati, OH, March 1978.
- 3. C. Cowherd, Jr., et al., Iron And Steel Plant Open Dust Source Fugitive Emission Evaluation, EPA-600/2-79-103, U. S. Environmental Protection Agency, Cincinnati, OH, May 1979.
- 4. Evaluation Of Open Dust Sources In The Vicinity Of Buffalo, New York, EPA Contract No. 68-02-2545, Midwest Research Institute, Kansas City, MO, March 1979.
- 5. C. Cowherd, Jr., and T. Cuscino, Jr., Fugitive Emissions Evaluation, MRI-4343-L, Midwest Research Institute, Kansas City, MO, February 1977.
- 6. T. Cuscino, Jr., et al., Taconite Mining Fugitive Emissions Study, Minnesota Pollution Control Agency, Roseville, MN, June 1979.

- Improved Emission Factors For Fugitive Dust From Western Surface Coal Mining Sources, 2 Volumes, EPA Contract No. 68-03-2924, PEDCo Environmental, Kansas City, MO, and Midwest Research Institute, Kansas City, MO, July 1981.
- 8. Determination Of Fugitive Coal Dust Emissions From Rotary Railcar Dumping, TRC, Hartford, CT, May 1984.
- 9. *PM-10 Emission Inventory Of Landfills In the Lake Calumet Area*, EPA Contract No. 68-02-3891, Midwest Research Institute, Kansas City, MO, September 1987.
- 10. Chicago Area Particulate Matter Emission Inventory Sampling And Analysis, EPA Contract No. 68-02-4395, Midwest Research Institute, Kansas City, MO, May 1988.
- 11. Update Of Fugitive Dust Emission Factors In AP-42 Section 11.2, EPA Contract No. 68-02-3891, Midwest Research Institute, Kansas City, MO, July 1987.
- 12. G. A. Jutze, et al., Investigation Of Fugitive Dust Sources Emissions And Control, EPA-450/3-74-036a, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.
- 13. C. Cowherd, Jr., et al., Control Of Open Fugitive Dust Sources, EPA-450/3-88-008, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.
13.2.5 Industrial Wind Erosion

13.2.5.1 General¹⁻³

Dust emissions may be generated by wind erosion of open aggregate storage piles and exposed areas within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with nonerodible elements (particles larger than approximately 1 centimeter [cm] in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that (a) threshold wind speeds exceed 5 meters per second (m/s) (11 miles per hour [mph]) at 15 cm above the surface or 10 m/s (22 mph) at 7 m above the surface, and (b) particulate emission rates tend to decay rapidly (half-life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential.

13.2.5.2 Emissions And Correction Parameters

If typical values for threshold wind speed at 15 cm are corrected to typical wind sensor height (7 - 10 m), the resulting values exceed the upper extremes of hourly mean wind speeds observed in most areas of the country. In other words, mean atmospheric wind speeds are not sufficient to sustain wind erosion from flat surfaces of the type tested. However, wind gusts may quickly deplete a substantial portion of the erosion potential. Because erosion potential has been found to increase rapidly with increasing wind speed, estimated emissions should be related to the gusts of highest magnitude.

The routinely measured meteorological variable that best reflects the magnitude of wind gusts is the fastest mile. This quantity represents the wind speed corresponding to the whole mile of wind movement that has passed by the 1 mile contact anemometer in the least amount of time. Daily measurements of the fastest mile are presented in the monthly Local Climatological Data (LCD) summaries. The duration of the fastest mile, typically about 2 minutes (for a fastest mile of 30 mph), matches well with the half-life of the erosion process, which ranges between 1 and 4 minutes. It should be noted, however, that peak winds can significantly exceed the daily fastest mile.

The wind speed profile in the surface boundary layer is found to follow a logarithmic distribution:

$$u(z) = \frac{u^*}{0.4} \ln \frac{z}{z_0} \qquad (z > z_0)$$
 (1)

where:

u = wind speed, cm/s $u^* = friction velocity, cm/s$

- z = height above test surface, cm
- $z_0 = roughness height, cm$
- 0.4 = von Karman's constant, dimensionless

The friction velocity (u^*) is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_0) is a measure of the roughness of the exposed surface as determined from the y intercept of the velocity profile, i. e., the height at which the wind speed is zero. These parameters are illustrated in Figure 13.2.5-1 for a roughness height of 0.1 cm.



Figure 13.2.5-1. Illustration of logarithmic velocity profile.

Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface because each time that a surface is disturbed, its erosion potential is restored. A disturbance is defined as an action that results in the exposure of fresh surface material. On a storage pile, this would occur whenever aggregate material is either added to or removed from the old surface. A disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest pieces of material present.

13.2.5.3 Predictive Emission Factor Equation⁴

The emission factor for wind-generated particulate emissions from mixtures of erodible and nonerodible surface material subject to disturbance may be expressed in units of grams per square meter (g/m^2) per year as follows:

Emission factor = k
$$\sum_{i=1}^{N} P_i$$
 (2)

where:

- $\mathbf{k} =$ particle size multiplier
- N = number of disturbances per year
- P_i = erosion potential corresponding to the observed (or probable) fastest mile of wind for the ith period between disturbances, g/m^2

The particle size multiplier (k) for Equation 2 varies with aerodynamic particle size, as follows:

Aerodynamic Particle Size Multipliers For Equation 2									
30 μm <15 μm <10 μm <2.5 μm									
1.0	0.6	0.5	0.2						

This distribution of particle size within the under 30 micrometer (μm) fraction is comparable to the distributions reported for other fugitive dust sources where wind speed is a factor. This is illustrated, for example, in the distributions for batch and continuous drop operations encompassing a number of test aggregate materials (see Section 13.2.4).

In calculating emission factors, each area of an erodible surface that is subject to a different frequency of disturbance should be treated separately. For a surface disturbed daily, N = 365 per year, and for a surface disturbance once every 6 months, N = 2 per year.

The erosion potential function for a dry, exposed surface is:

$$P = 58 (u^* - u_t^*)^2 + 25 (u^* - u_t^*)$$

$$P = 0 \text{ for } u^* \le u_t^*$$
(3)

where:

u^{*} = friction velocity (m/s) u_t = threshold friction velocity (m/s)

Because of the nonlinear form of the erosion potential function, each erosion event must be treated separately.

Equations 2 and 3 apply only to dry, exposed materials with limited erosion potential. The resulting calculation is valid only for a time period as long or longer than the period between disturbances. Calculated emissions represent intermittent events and should not be input directly into dispersion models that assume steady-state emission rates.

For uncrusted surfaces, the threshold friction velocity is best estimated from the dry aggregate structure of the soil. A simple hand sieving test of surface soil can be used to determine the mode of the surface aggregate size distribution by inspection of relative sieve catch amounts, following the procedure described below.

FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY (from a 1952 laboratory procedure published by W. S. Chepil):

- 1. Prepare a nest of sieves with the following openings: 4 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm. Place a collector pan below the bottom (0.25 mm) sieve.
- 2. Collect a sample representing the surface layer of loose particles (approximately 1 cm in depth, for an encrusted surface), removing any rocks larger than about 1 cm in average physical diameter. The area to be sampled should be not less than 30 cm by 30 cm.
- 3. Pour the sample into the top sieve (4-mm opening), and place a lid on the top.
- 4. Move the covered sieve/pan unit by hand, using a broad circular arm motion in the horizontal plane. Complete 20 circular movements at a speed just necessary to achieve some relative horizontal motion between the sieve and the particles.
- 5. Inspect the relative quantities of catch within each sieve, and determine where the mode in the aggregate size distribution lies, i. e., between the opening size of the sieve with the largest catch and the opening size of the next largest sieve.
- 6. Determine the threshold friction velocity from Table 13.2.5-1.

The results of the sieving can be interpreted using Table 13.2.5-1. Alternatively, the threshold friction velocity for erosion can be determined from the mode of the aggregate size distribution using the graphical relationship described by Gillette.⁵⁻⁶ If the surface material contains nonerodible elements that are too large to include in the sieving (i. e., greater than about 1 cm in diameter), the effect of the elements must be taken into account by increasing the threshold friction velocity.¹⁰

Tyler Sieve No.	Opening (mm)	Midpoint (mm)	^u [*] _t (cm/s)
5	4		
9	2	3	100
16	1	1.5	76
32	0.5	0.75	58
60	0.25	0.375	43

Table 13.2.5-1 (Metric Units). FIELD PROCEDURE FOR DETERMINATION OF THRESHOLD FRICTION VELOCITY

Threshold friction velocities for several surface types have been determined by field measurements with a portable wind tunnel. These values are presented in Table 13.2.5-2.

	Threshold Friction		Threshold Wi 10 m	nd Velocity At (m/s)
Material	Velocity (m/s)	Roughness Height (cm)	$z_o = Act$	$z_{o} = 0.5 \text{ cm}$
Overburden ^a	1.02	0.3	21	19
Scoria (roadbed material) ^a	1.33	0.3	27	25
Ground coal (surrounding coal pile) ^a	0.55	0.01	16	10
Uncrusted coal pile ^a	1.12	0.3	23	21
Scraper tracks on coal pile ^{a,b}	0.62	0.06	15	12
Fine coal dust on concrete pad ^e	0.54	0.2	11	10

Table 13.2.5-2 (Metric Units). THRESHOLD FRICTION VELOCITIES

^a Western surface coal mine. Reference 2.

^b Lightly crusted.

^c Eastern power plant. Reference 3.

The fastest mile of wind for the periods between disturbances may be obtained from the monthly LCD summaries for the nearest reporting weather station that is representative of the site in question.⁷ These summaries report actual fastest mile values for each day of a given month. Because the erosion potential is a highly nonlinear function of the fastest mile, mean values of the fastest mile are inappropriate. The anemometer heights of reporting weather stations are found in Reference 8, and should be corrected to a 10-m reference height using Equation 1.

To convert the fastest mile of wind (u^+) from a reference anemometer height of 10 m to the equivalent friction velocity (u^*) , the logarithmic wind speed profile may be used to yield the following equation:

$$u^* = 0.053 u_{10}^+$$
 (4)

where:

 $u^* = friction velocity (m/s)$

 u_{10}^{+} = fastest mile of reference anemometer for period between disturbances (m/s)

This assumes a typical roughness height of 0.5 cm for open terrain. Equation 4 is restricted to large relatively flat piles or exposed areas with little penetration into the surface wind layer.

If the pile significantly penetrates the surface wind layer (i. e., with a height-to-base ratio exceeding 0.2), it is necessary to divide the pile area into subareas representing different degrees of exposure to wind. The results of physical modeling show that the frontal face of an elevated pile is exposed to wind speeds of the same order as the approach wind speed at the top of the pile.

Miscellaneous Sources

For 2 representative pile shapes (conical and oval with flattop, 37-degree side slope), the ratios of surface wind speed (u_s) to approach wind speed (u_r) have been derived from wind tunnel studies.⁹ The results are shown in Figure 13.2.5-2 corresponding to an actual pile height of 11 m, a reference (upwind) anemometer height of 10 m, and a pile surface roughness height (z_o) of 0.5 cm. The measured surface winds correspond to a height of 25 cm above the surface. The area fraction within each contour pair is specified in Table 13.2.5-3.

	Percent Of Pile Surface Area									
Pile Subarea	Pile A	Pile B1	Pile B2	Pile B3						
0.2a	5	5	3	3						
0.2b	35	2	28	25						
0.2c	NA	29	NA	NA						
0.6a	48	26	29	28						
0.6b	NA	24	22	26						
0.9	12	14	15	14						
1.1	NA	NA	3	4						

Table 13.2.5-3. SUBAREA DISTRIBUTION FOR REGIMES OF u_s/u_r^a

^a NA = not applicable.

The profiles of u_s/u_r in Figure 13.2.5-2 can be used to estimate the surface friction velocity distribution around similarly shaped piles, using the following procedure:

1. Correct the fastest mile value (u⁺) for the period of interest from the anemometer height (z) to a reference height of 10 m u₁₀⁺ using a variation of Equation 1:

$$u_{10}^{+} = u^{+} \frac{\ln (10/0.005)}{\ln (z/0.005)}$$
(5)

where a typical roughness height of 0.5 cm (0.005 m) has been assumed. If a site-specific roughness height is available, it should be used.

2. Use the appropriate part of Figure 13.2.5-2 based on the pile shape and orientation to the fastest mile of wind, to obtain the corresponding surface wind speed distribution (u_s^+)

$$u_{s}^{+} = \frac{(u_{s})}{u_{r}} \quad u_{10}^{+}$$
 (6)





Figure 13.2.5-2. Contours of normalized surface windspeeds, u_s/u_r .

Miscellaneous Sources

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3. For any subarea of the pile surface having a narrow range of surface wind speed, use a variation of Equation 1 to calculate the equivalent friction velocity (u^{*}):

$$u^{*} = \frac{0.4u_{s}^{+}}{\frac{25}{100.5}} = 0.10u_{s}^{+}$$
(7)

From this point on, the procedure is identical to that used for a flat pile, as described above.

Implementation of the above procedure is carried out in the following steps:

- 1. Determine threshold friction velocity for erodible material of interest (see Table 13.2.5-2 or determine from mode of aggregate size distribution).
- 2. Divide the exposed surface area into subareas of constant frequency of disturbance (N).
- 3. Tabulate fastest mile values (u^+) for each frequency of disturbance and correct them to 10 m (u_{10}^+) using Equation 5.5
- 4. Convert fastest mile values (u₁₀) to equivalent friction velocities (u^{*}), taking into account (a) the uniform wind exposure of nonelevated surfaces, using Equation 4, or (b) the nonuniform wind exposure of elevated surfaces (piles), using Equations 6 and 7.
- 5. For elevated surfaces (piles), subdivide areas of constant N into subareas of constant u^* (i. e., within the isopleth values of u_s/u_r in Figure 13.2.5-2 and Table 13.2.5-3) and determine the size of each subarea.
- 6. Treating each subarea (of constant N and u^{*}) as a separate source, calculate the erosion potential (P_i) for each period between disturbances using Equation 3 and the emission factor using Equation 2.
- 7. Multiply the resulting emission factor for each subarea by the size of the subarea, and add the emission contributions of all subareas. Note that the highest 24-hour (hr) emissions would be expected to occur on the windiest day of the year. Maximum emissions are calculated assuming a single event with the highest fastest mile value for the annual period.

The recommended emission factor equation presented above assumes that all of the erosion potential corresponding to the fastest mile of wind is lost during the period between disturbances. Because the fastest mile event typically lasts only about 2 minutes, which corresponds roughly to the half-life for the decay of actual erosion potential, it could be argued that the emission factor overestimates particulate emissions. However, there are other aspects of the wind erosion process that offset this apparent conservatism:

1. The fastest mile event contains peak winds that substantially exceed the mean value for the event.

2. Whenever the fastest mile event occurs, there are usually a number of periods of slightly lower mean wind speed that contain peak gusts of the same order as the fastest mile wind speed.

Of greater concern is the likelihood of overprediction of wind erosion emissions in the case of surfaces disturbed infrequently in comparison to the rate of crust formation.

13.2.5.4 Example 1: Calculation for wind erosion emissions from conically shaped coal pile

A coal burning facility maintains a conically shaped surge pile 11 m in height and 29.2 m in base diameter, containing about 2000 megagrams (Mg) of coal, with a bulk density of 800 kilograms per cubic meter (kg/m³⁾ (50 pounds per cubic feet [lb/ft³]). The total exposed surface area of the pile is calculated as follows:

$$S = \underline{\pi} r (r^{2} + h^{2})$$

= 3.14(14.6) (14.6)² + (11.0)²
= 838 m²

Coal is added to the pile by means of a fixed stacker and reclaimed by front-end loaders operating at the base of the pile on the downwind side. In addition, every 3 days 250 Mg (12.5 percent of the stored capacity of coal) is added back to the pile by a topping off operation, thereby restoring the full capacity of the pile. It is assumed that (a) the reclaiming operation disturbs only a limited portion of the surface area where the daily activity is occurring, such that the remainder of the pile surface remains intact, and (b) the topping off operation creates a fresh surface on the entire pile while restoring its original shape in the area depleted by daily reclaiming activity.

Because of the high frequency of disturbance of the pile, a large number of calculations must be made to determine each contribution to the total annual wind erosion emissions. This illustration will use a single month as an example.

<u>Step 1</u>: In the absence of field data for estimating the threshold friction velocity, a value of 1.12 m/s is obtained from Table 13.2.5-2.

<u>Step 2</u>: Except for a small area near the base of the pile (see Figure 13.2.5-3), the entire pile surface is disturbed every 3 days, corresponding to a value of N = 120 per year. It will be shown that the contribution of the area where daily activity occurs is negligible so that it does not need to be treated separately in the calculations.

Step 3: The calculation procedure involves determination of the fastest mile for each period of disturbance. Figure 13.2.5-4 shows a representative set of values (for a 1-month period) that are assumed to be applicable to the geographic area of the pile location. The values have been separated into 3-day periods, and the highest value in each period is indicated. In this example, the anemometer height is 7 m, so that a height correction to 10 m is needed for the fastest mile values. From Equation 5, (1-(10/0.005))

$$u_{10}^{+} = u_{7}^{+} \left[\frac{\ln (10/0.005)}{\ln (7/0.005)} \right]$$
$$u_{10}^{+} = 1.05 \ u_{7}^{+}$$

4



* A portion of C_2 is disturbed daily by reclaiming activities.

		Pile	<u>le Surface</u>		
Area ID	us Ur	x	Area (m ²)		
A	0.9	12		101	
В	0.6	48		402	
c ₁ + c ₂	0.2	40		<u>335</u>	
			Total	838	

Figure 13.2.5-3. Example 1: Pile surface areas within each wind speed regime.





MONTHLY SUMMARY

:		HIND			Ĺ!	
Ë		50	FAS MI	TEST		
RESULTANT D	RESULTANT SPEED H.P.H	AVERAGE SPE M.P.H.	SPEE0 Н.Р.И.	DIRECTION		DATE
13	14	15	16	17		22
30 01 10 13 12 29 29 22 14 29 29 22 14 29 22 14 29 22 29 22 14 29 27 21 10 10 13 27 29 22 29 22 24 29 27 29 22 24 29 27 27 27 27 27 27 27 27 27 27	5.3 10.5 2.4 11.0 11.3 11.1 19.6 22.3 7.9 7.7 4.5 6.7 13.7 11.2 4.3 7.5 10.3 17.1 4.3 7.5 10.3 17.1 8.3 8.2 5.0 3.1 8.2 5.0 3.1 8.2 5.0 3.1 9.3	6.9 10.6 6.0 11.4 19.0 19.8 11.2 8.1 15.1 9.6 8.8 13.8 13.8 13.8 13.8 13.8 13.8 13.8 13.5 8.8 13.8 13.5 8.8 13.8 10.6 17.3 8.5 8.8 11.2 5.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.8 11.5 8.5 8.8 11.5 8.5 8.8 11.5 8.5 8.8 11.5 8.5 8.8 11.5 8.5 8.8 11.5 8.5 8.8 11.5 8.5 8.5 10.6 5.5 8.5 10.5 8.5 10.5 8.5 10.5 8.5 8.5 10.5 8.5 10.5 8.5 10.5 8.5 10.5 8.5 10.5 8.5 10.5 10.5 8.5 10		36 01 02 13 11 30 30 13 29 17 18 31 31 32 12 29 17 18 31 32 32 32 32 32 32 32 32 32 32 32 32 32		1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 1 2 3 4 5 6 7 8 9 0 1 2 2 2 3 4 5 6 7 8 9 0 1 2 2 3 4 5 6 7 8 9 0 1 2 2 3 3 3 1 2 2 2 3 4 5 6 7 8 9 0 1 2 3 3 3 1 2 2 3 4 5 6 7 8 9 0 1 2 3 3 3 1 2 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 2 3 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1
30			DATE	11	-	1

Figure 13.2.5-4. Example daily fastest miles wind for periods of interest.

Miscellaneous Sources

Step 4: The next step is to convert the fastest mile value for each 3-day period into the equivalent friction velocities for each surface wind regime (i. e., u_s/u_r ratio) of the pile, using Equations 6 and 7. Figure 13.2.5-3 shows the surface wind speed pattern (expressed as a fraction of the approach wind speed at a height of 10 m). The surface areas lying within each wind speed regime are tabulated below the figure.

The calculated friction velocities are presented in Table 13.2.5-4. As indicated, only 3 of the periods contain a friction velocity which exceeds the threshold value of 1.12 m/s for an uncrusted coal pile. These 3 values all occur within the $u_s/u_r = 0.9$ regime of the pile surface.

	u	+ 7	u ⁺ ₁₀		$u^* = 0.1u_S^+ (m/s)$			
3-Day Period	mph	m/s	mph	m/s	u _s /u _r : 0.2	u _s /u _r : 0.6	u _s /u _r : 0.9	
1	14	6.3	15	6.6	0.13	0.40	0.59	
2	29	13.0	31	13.7	0.27	0.82	1.23	
3	30	13.4	32	14.1	0.28	0.84	1.27	
4	31	13.9	33	14.6	0.29	0.88	1.31	
5	22	9.8	23	10.3	0.21	0.62	0.93	
6	21	9.4	22	9.9	0.20	0.59	0.89	
7	16	7.2	17	7.6	0.15	0.46	0.68	
8	25	11.2	26	11.8	0.24	0.71	1.06	
9	17	7.6	18	8.0	0.16	0.48	0.72	
10	13	5.8	14	6.1	0.12	0.37	0.55	

Table 13.2.5-4 (Metric And English Units).EXAMPLE 1:CALCULATION OF FRICTION VELOCITIES

<u>Step 5</u>: This step is not necessary because there is only 1 frequency of disturbance used in the calculations. It is clear that the small area of daily disturbance (which lies entirely within the $u_s/u_r = 0.2$ regime) is never subject to wind speeds exceeding the threshold value.

<u>Steps 6 and 7</u>: The final set of calculations (shown in Table 13.2.5-5) involves the tabulation and summation of emissions for each disturbance period and for the affected subarea. The erosion potential (P) is calculated from Equation 3.

For example, the calculation for the second 3-day period is:

$$P = 58(u^* - u_t^*)^2 + 25(u^* - u_t^*)$$

$$P_2 = 58(1.23 - 1.12)^2 + 25(1.23 - 1.12)$$

$$= 0.70 + 2.75 = 3.45 \text{ g/m}^2$$

3-Day Period	u* (m/s)	u* - u _t * (m/s)	P (g/m ²)	ID	Pile Surface Area (m ²)	kPA (g)
2	1.23	0.11	3.45	Α	101	170
3	1.27	0.15	5.06	A	101	260
4	1.31	0.19	6.84	A	101	350
TOTAL						780

Table 13.2.5-5 (Metric Units). EXAMPLE 1: CALCULATION OF PM-10 EMISSIONS^a

^a Where $u_t^* = 1.12$ m/s for uncrusted coal and k = 0.5 for PM-10.

The emissions of particulate matter greater than 10 μ m (PM-10) generated by each event are found as the product of the PM-10 multiplier (k = 0.5), the erosion potential (P), and the affected area of the pile (A).

As shown in Table 13.2.5-5, the results of these calculations indicate a monthly PM-10 emission total of 780 g.

13.2.5.5 Example 2: Calculation for wind erosion from flat area covered with coal dust

A flat circular area 29.2 m in diameter is covered with coal dust left over from the total reclaiming of a conical coal pile described in the example above. The total exposed surface area is calculated as follows:

 $s = \frac{\pi}{4} d^2 = 0.785 (29.2)^2 = 670 m^2$

This area will remain exposed for a period of 1 month when a new pile will be formed.

<u>Step 1</u>: In the absence of field data for estimating the threshold friction velocity, a value of 0.54 m/s is obtained from Table 13.2.5-2.

<u>Step 2</u>: The entire surface area is exposed for a period of 1 month after removal of a pile and N = 1/yr.

<u>Step 3</u>: From Figure 13.2.5-4, the highest value of fastest mile for the 30-day period (31 mph) occurs on the 11th day of the period. In this example, the reference anemometer height is 7 m, so that a height correction is needed for the fastest mile value. From Step 3 of the previous example, $u_{10}^+ = 1.05 u_7^+$, so that $u_{10}^+ = 33$ mph.

<u>Step 4</u>: Equation 4 is used to convert the fastest mile value of 14.6 m/s (33 mph) to an equivalent friction velocity of 0.77 m/s. This value exceeds the threshold friction velocity from Step 1 so that erosion does occur.

<u>Step 5</u>: This step is not necessary, because there is only 1 frequency of disturbance for the entire source area.

Miscellaneous Sources

<u>Steps 6 and 7</u>: The PM-10 emissions generated by the erosion event are calculated as the product of the PM-10 multiplier (k = 0.5), the erosion potential (P) and the source area (A). The erosion potential is calculated from Equation 3 as follows:

$$P = 58(u^* - u_t^*)^2 + 25(u^* - u_t^*)$$

$$P = 58(0.77 - 0.54)^2 + 25(0.77 - 0.54)$$

$$= 3.07 + 5.75$$

$$= 8.82 \text{ g/m}^2$$

Thus the PM-10 emissions for the 1-month period are found to be:

$$E = (0.5)(8.82 \text{ g/m}^2)(670 \text{ m}^2)$$
$$= 3.0 \text{ kg}$$

References For Section 13.2.5

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13.3 Explosives Detonation

13.3.1 General¹⁻⁵

This section deals mainly with pollutants resulting from the detonation of industrial explosives and firing of small arms. Military applications are excluded from this discussion. Emissions associated with the manufacture of explosives are treated in Section 6.3, "Explosives".

An explosive is a chemical material that is capable of extremely rapid combustion resulting in an explosion or detonation. Since an adequate supply of oxygen cannot be drawn from the air, a source of oxygen must be incorporated into the explosive mixture. Some explosives, such as trinitrotoluene (TNT), are single chemical species, but most explosives are mixtures of several ingredients. "Low explosive" and "high explosive" classifications are based on the velocity of explosion, which is directly related to the type of work the explosive can perform. There appears to be no direct relationship between the velocity of explosions and the end products of explosive reactions. These end products are determined primarily by the oxygen balance of the explosive. As in other combustion reactions, a deficiency of oxygen favors the formation of carbon monoxide and unburned organic compounds and produces little, if any, nitrogen oxides. An excess of oxygen causes more nitrogen oxides and less carbon monoxide and other unburned organics. For ammonium nitrate and fuel oil (ANFO) mixtures, a fuel oil content of more than 5.5 percent creates a deficiency of oxygen.

There are hundreds of different explosives, with no universally accepted system for classifying them. The classification used in Table 13.3-1 is based on the chemical composition of the explosives, without regard to other properties, such as rate of detonation, which relate to the applications of explosives but not to their specific end products. Most explosives are used in 2-, 3-, or 4-step trains that are shown schematically in Figure 13.3-1. The simple removal of a tree stump might be done with a 2-step train made up of an electric blasting cap and a stick of dynamite. The detonation wave from the blasting cap would cause detonation of the dynamite. To make a large hole in the earth, an inexpensive explosive such as ANFO might be used. In this case, the detonation wave from the blasting cap is not powerful enough to cause detonation, so a booster must be used in a 3- or 4-step train. Emissions from the blasting caps and safety fuses used in these trains are usually small compared to those from the main charge makes up most of the total weight. No factors are given for computing emissions from blasting caps or fuses, because these have not been measured, and because the uncertainties are so great in estimating emissions from the main and booster charges that a precise estimate of all emissions is not practical.

13.3.2 Emissions And Controls^{2,4-6}

Carbon monoxide is the pollutant produced in greatest quantity from explosives detonation. TNT, an oxygen-deficient explosive, produces more CO than most dynamites, which are oxygenbalanced. But all explosives produce measurable amounts of CO. Particulates are produced as well, but such large quantities of particulate are generated in the shattering of the rock and earth by the explosive that the quantity of particulates from the explosive charge cannot be distinguished. Nitrogen oxides (both nitric oxide [NO] and nitrogen dioxide [NO₂]) are formed, but only limited data are available on these emissions. Oxygen-deficient explosives are said to produce little or no

Table 13.3-1 (Metric And English Units). EMISSION FACTORS FOR DETONATION OF EXPLOSIVES

			Carbon M	onoxide ^a	Nitrogen Oxides ^a		Methane ^b		Other		
Explosive	Composition	Uses	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Pollutant	kg/Mg	lb/ton
Black powder ²	75/15/10; Potassium (sodium) nitrate/ charcoal sulfur	Delay fuses	85 (38-120)	170 (76-240)	ND	ND	2.1 (0.3-4.9)	4.2 (0.6-9.7)	H ₂ S	12 (0-37)	24 (0-73)
Smokeless powder ²	Nitrocellulose (sometimes with other materials)	Small arms, propellant	38 (34-42)	77 (68-84)	ND	ND	0.6 (0.4-0.6)	1.1 (0.7-1.5)	H ₂ S Pb	1 0 (10-11) c	21 (20-21) °
Dynamite, straight ²	20-60% Nitroglycerine/ sodium nitrate/ wood pulp/ calcium carbonate	Rarely used	141 (44-262)	281 (87-524)	ND	ND	1.3 (0.3-2.8)	2.5 (0.6-5.6)	H ₂ S	3 (0-7)	6 (0-15)
Dynamite, ammonia ²	20-60% Nitroglycerine/ ammonium nitrate/sodium nitrate/wood pulp	Quarry work, stump blasting	32 (23-64)	63 (46-128)	ND	ND	0.7 (0.3-1.1)	1.3 (0.6-2.1)	H ₂ S	16 (9-19)	31 (19-37)
Dynamite, gelatin ²	20-100% Nitroglycerine	Demolition, construction work, blasting in mines	52 (13-110)	104 (26-220)	26 (4-59)	53 (8-119)	0.3 (0.1-0.8)	0.7 (0.3-1.7)	H ₂ S SO ₂	2 (0-3) 1 (0-8)	4 (0-6) 1 (1-16)

EMISSION FACTOR RATING: D

Miscellaneous	
Sources	

Table 13.3-1 (cont.).	
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			Carbon Monoxide ^a		Carbon Monoxide ^a Nitrogen Oxides ^a		Ме	Methane ^b		Other	
Explosive	Composition	Uses	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	Pollutant	kg/Mg	lb/ton
ANFO ^{4,5}	Ammonium nitrate with 5.8-8% fuel oil	Construction work, blasting in mines	34	67	8	17	ND	ND	SO2	1 (0-2)	2 (1-3)
TNT ²	Trinitrotoluene	Main charge in artillery projectiles, mortar rounds, etc.	398 (324-472)	796 (647-944)	ND	ND	7.2 (6.6-7.7)	14.3 (13.2-15.4)	NH3 HCN C2H2 C2H6	14 (14-15) 13 (11-16) 61 0.5	29 (27-30) 27 (22-32) 121 1.1
RDX ³	(CH ₂) ₃ N ₃ (NO ₂) ₃ Cyclotri- methylene- trinitroamine	Booster	98 ^d (2.8-277)	196 ^d (5.6-554)	ND	ND	ND	ND	NH3	22 ^d (12-61)	44 ^d (24-122)
PETN ²	C(CH ₂ ONO ₂) ₄ Pentaerythritol tetranitrate	Booster	149 (138-160)	297 (276-319)	ND	ND	ND	ND	NH3	1.3 (0-25)	2.5 (0-5)

^a Based on experiments carried out prior to 1930 except in the case of ANFO, TNT, and PETN. ND = no data.
 ^b The factors apply to the chemical species, methane. They do not represent total volatile organic compounds (VOC) expressed as methane. Studies were carried out more than 40 years ago.
 ^c Greater than 6 mg per 158 grain projectile (0.6 kg/Mg, 1.2 lb/ton).
 ^d These factors are derived from theoretical calculations, not from experimental data.



a. Two-step explosive train



b. Three-step explosive train



c. Four-step explosive train

Figure 13.3-1. Two-, three-, and four-step explosive trains.

nitrogen oxides, but there is only a small body of data to confirm this. Unburned hydrocarbons also result from explosions, but in most instances, methane is the only species that has been reported.

Hydrogen sulfide, hydrogen cyanide, and ammonia all have been reported as products of explosives use. Lead is emitted from the firing of small arms ammunition with lead projectiles and/or lead primers, but the explosive charge does not contribute to the lead emissions.

The emissions from explosives detonation are influenced by many factors such as explosive composition, product expansion, method of priming, length of charge, and confinement. These factors are difficult to measure and control in the field and are almost impossible to duplicate in a laboratory test facility. With the exception of a few studies in underground mines, most studies have been performed in laboratory test chambers that differ substantially from the actual environment. Any estimates of emissions from explosives use must be regarded as approximations that cannot be made more precise because explosives are not used in a precise, reproducible manner.

To a certain extent, emissions can be altered by changing the composition of the explosive mixture. This has been practiced for many years to safeguard miners who must use explosives. The U. S. Bureau of Mines has a continuing program to study the products from explosives and to identify explosives that can be used safely underground. Lead emissions from small arms use can be controlled by using jacketed soft-point projectiles and special leadfree primers.

Emission factors are given in Table 13.3-1. Factors are expressed in units of kilograms per megagram (kg/Mg) and pounds per ton (lb/ton).

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13.4 Wet Cooling Towers

13.4.1 General¹

Cooling towers are heat exchangers that are used to dissipate large heat loads to the atmosphere. They are used as an important component in many industrial and commercial processes needing to dissipate heat. Cooling towers may range in size from less than $5.3(10)^6$ kilojoules (kJ) $(5[10]^6$ British thermal units per hour [Btu/hr]) for small air conditioning cooling towers to over $5275(10)^6$ kJ/hr ($5000[10^6]$ Btu/hr) for large power plant cooling towers.

When water is used as the heat transfer medium, wet, or evaporative, cooling towers may be used. Wet cooling towers rely on the latent heat of water evaporation to exchange heat between the process and the air passing through the cooling tower. The cooling water may be an integral part of the process or may provide cooling via heat exchangers.

Although cooling towers can be classified several ways, the primary classification is into dry towers or wet towers, and some hybrid wet-dry combinations exist. Subclassifications can include the draft type and/or the location of the draft relative to the heat transfer medium, the type of heat transfer medium, the relative direction of air movement, and the type of water distribution system.

In wet cooling towers, heat transfer is measured by the decrease in the process temperature and a corresponding increase in both the moisture content and the wet bulb temperature of the air passing through the cooling tower. (There also may be a change in the sensible, or dry bulb, temperature, but its contribution to the heat transfer process is very small and is typically ignored when designing wet cooling towers.) Wet cooling towers typically contain a wetted medium called "fill" to promote evaporation by providing a large surface area and/or by creating many water drops with a large cumulative surface area.

Cooling towers can be categorized by the type of heat transfer; the type of draft and location of the draft, relative to the heat transfer medium; the type of heat transfer medium; the relative direction of air and water contact; and the type of water distribution system. Since wet, or evaporative, cooling towers are the dominant type, and they also generate air pollutants, this section will address only that type of tower. Diagrams of the various tower configurations are shown in Figure 13.4-1 and Figure 13.4-2.

13.4.2 Emissions And Controls¹

Because wet cooling towers provide direct contact between the cooling water and the air passing through the tower, some of the liquid water may be entrained in the air stream and be carried out of the tower as "drift" droplets. Therefore, the particulate matter constituent of the drift droplets may be classified as an emission.

The magnitude of drift loss is influenced by the number and size of droplets produced within the cooling tower, which in turn are determined by the fill design, the air and water patterns, and other interrelated factors. Tower maintenance and operation levels also can influence the formation of drift droplets. For example, excessive water flow, excessive airflow, and water bypassing the tower drift eliminators can promote and/or increase drift emissions.



Figure 13.4-1 Atmospheric and natural draft cooling towers.

Because the drift droplets generally contain the same chemical impurities as the water circulating through the tower, these impurities can be converted to airborne emissions. Large drift droplets settle out of the tower exhaust air stream and deposit near the tower. This process can lead to wetting, icing, salt deposition, and related problems such as damage to equipment or to vegetation. Other drift droplets may evaporate before being deposited in the area surrounding the tower, and they also can produce PM-10 emissions. PM-10 is generated when the drift droplets evaporate and leave fine particulate matter formed by crystallization of dissolved solids. Dissolved solids found in cooling tower drift can consist of mineral matter, chemicals for corrosion inhibition, etc.



Figure 13.4-2. Mechanical draft cooling towers.

To reduce the drift from cooling towers, drift eliminators are usually incorporated into the tower design to remove as many droplets as practical from the air stream before exiting the tower. The drift eliminators used in cooling towers rely on inertial separation caused by direction changes while passing through the eliminators. Types of drift eliminator configurations include herringbone (blade-type), wave form, and cellular (or honeycomb) designs. The cellular units generally are the most efficient. Drift eliminators may include various materials, such as ceramics, fiber reinforced cement, fiberglass, metal, plastic, and wood installed or formed into closely spaced slats, sheets, honeycomb assemblies, or tiles. The materials may include other features, such as corrugations and water removal channels, to enhance the drift removal further.

Table 13.4-1 provides available particulate emission factors for wet cooling towers. Separate emission factors are given for induced draft and natural draft cooling towers. Several features in Table 13.4-1 should be noted. First, a *conservatively high* PM-10 emission factor can be obtained by (a) multiplying the total liquid drift factor by the total dissolved solids (TDS) fraction in the circulating water and (b) assuming that, once the water evaporates, all remaining solid particles are within the PM-10 size range.

Second, if TDS data for the cooling tower are not available, a source-specific TDS content can be estimated by obtaining the TDS data for the make-up water and multiplying them by the cooling tower cycles of concentration. The cycles of concentration ratio is the ratio of a measured

Table 13.4-1 (Metric And English Units). PARTICULATE EMISSIONS FACTORS FOR WET COOLING TOWERS^a

	Total Liquid Drift ^b			PM-10°			
Tower Type ^d	Circulating Water Flow ^b	g/daL	lb/10 ³ gal	EMISSION FACTOR RATING	g/daL ^e	lb/10 ³ gal	EMISSION FACTOR RATING
Induced Draft (SCC 3-85-001-01, 3-85-001-20, 3-85-002-01)	0.020	2.0	1.7	D	0.023	0.019	Е
Natural Draft (SCC 3-85-001-02, 3-85-002-02)	0.00088	0.088	0.073	Е	ND	ND	—

^a References 1-17. Numbers are given to 2 significant digits. ND = no data. SCC = Source Classification Code.

^b References 2,5-7,9-10,12-13,15-16. Total liquid drift is water droplets entrained in the cooling tower exit air stream. Factors are for % of circulating water flow (10⁻² L drift/L [10⁻² gal drift/gal] water flow) and g drift/daL (lb drift/10³ gal) circulating water flow.
0.12 g/daL = 0.1 lb/10³ gal; 1 daL = 10¹ L.

^c See discussion in text on how to use the table to obtain PM-10 emission estimates. Values shown above are the arithmetic average of test results from References 2,4,8, and 11-14, and they imply an effective TDS content of approximately 12,000 parts per million (ppm) in the circulating water.

^d See Figure 13.4-1 and Figure 13.4-2. Additional SCCs for wet cooling towers of unspecified draft type are 3-85-001-10 and 3-85-002-10.

^e Expressed as g PM-10/daL (lb PM-10/10³ gal) circulating water flow.

parameter for the cooling tower water (such as conductivity, calcium, chlorides, or phosphate) to that parameter for the make-up water. This estimated cooling tower TDS can be used to calculate the PM-10 emission factor as above. If neither of these methods can be used, the arithmetic average PM-10 factor given in Table 13.4-1 can be used. Table 13.4-1 presents the arithmetic average PM-10 factor calculated from the test data in References 2, 4, 8, and 11 - 14. Note that this average corresponds to an effective cooling tower recirculating water TDS content of approximately 11,500 ppm for induced draft towers. (This can be found by dividing the total liquid drift factor into the PM-10 factor.)

As an alternative approach, if TDS data are unavailable for an induced draft tower, a value may be selected from Table 13.4-2 and then be combined with the total liquid drift factor in Table 13.4-1 to determine an apparent PM-10 factor.

As shown in Table 13.4-2, available data do not suggest that there is any significant difference between TDS levels in counter and cross flow towers. Data for natural draft towers are not available.

Table 13.4-2.SUMMARY STATISTICS FOR TOTAL DISSOLVED
SOLIDS (TDS) CONTENT IN CIRCULATING WATER^a

Type Of Draft	No. Of Cases	Range Of TDS Values (ppm)	Geometric Mean TDS Value (ppm)
Counter Flow	10	3700 - 55,000	18,500
Cross Flow	7	380 - 91,000	24,000
Overall ^b	17	380 - 91,000	20,600

^a References 2,4,8,11-14.

^b Data unavailable for natural draft towers.

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13.5 Industrial Flares

13.5.1 General

Flaring is a high-temperature oxidation process used to burn combustible components, mostly hydrocarbons, of waste gases from industrial operations. Natural gas, propane, ethylene, propylene, butadiene and butane constitute over 95 percent of the waste gases flared. In combustion, gaseous hydrocarbons react with atmospheric oxygen to form carbon dioxide (CO_2) and water. In some waste gases, carbon monoxide (CO) is the major combustible component. Presented below, as an example, is the combustion reaction of propane.

$$C_3H_8 + 5 O_2 \rightarrow 3 CO_2 + 4 H_2O$$

During a combustion reaction, several intermediate products are formed, and eventually, most are converted to CO_2 and water. Some quantities of stable intermediate products such as carbon monoxide, hydrogen, and hydrocarbons will escape as emissions.

Flares are used extensively to dispose of (1) purged and wasted products from refineries, (2) unrecoverable gases emerging with oil from oil wells, (3) vented gases from blast furnaces, (4) unused gases from coke ovens, and (5) gaseous wastes from chemical industries. Gases flared from refineries, petroleum production, chemical industries, and to some extent, from coke ovens, are composed largely of low molecular weight hydrocarbons with high heating value. Blast furnace flare gases are largely of inert species and CO, with low heating value. Flares are also used for burning waste gases generated by sewage digesters, coal gasification, rocket engine testing, nuclear power plants with sodium/water heat exchangers, heavy water plants, and ammonia fertilizer plants.

There are two types of flares, elevated and ground flares. Elevated flares, the more common type, have larger capacities than ground flares. In elevated flares, a waste gas stream is fed through a stack anywhere from 10 to over 100 meters tall and is combusted at the tip of the stack. The flame is exposed to atmospheric disturbances such as wind and precipitation. In ground flares, combustion takes place at ground level. Ground flares vary in complexity, and they may consist either of conventional flare burners discharging horizontally with no enclosures or of multiple burners in refractory-lined steel enclosures.

The typical flare system consists of (1) a gas collection header and piping for collecting gases from processing units, (2) a knockout drum (disentrainment drum) to remove and store condensables and entrained liquids, (3) a proprietary seal, water seal, or purge gas supply to prevent flash-back, (4) a single- or multiple-burner unit and a flare stack, (5) gas pilots and an ignitor to ignite the mixture of waste gas and air, and, if required, (6) a provision for external momentum force (steam injection or forced air) for smokeless flaring. Natural gas, fuel gas, inert gas, or nitrogen can be used as purge gas. Figure 13.5-1 is a diagram of a typical steam-assisted elevated smokeless flare system.

Complete combustion requires sufficient combustion air and proper mixing of air and waste gas. Smoking may result from combustion, depending upon waste gas components and the quantity and distribution of combustion air. Waste gases containing methane, hydrogen, CO, and ammonia usually burn without smoke. Waste gases containing heavy hydrocarbons such as paraffins above methane, olefins, and aromatics, cause smoke. An external momentum force, such as steam injection



Figure 13.5-1. Diagram of a typical steam-assisted smokeless elevated flare.

or blowing air, is used for efficient air/waste gas mixing and turbulence, which promotes smokeless flaring of heavy hydrocarbon waste gas. Other external forces may be used for this purpose, including water spray, high velocity vortex action, or natural gas. External momentum force is rarely required in ground flares.

Steam injection is accomplished either by nozzles on an external ring around the top of the flare tip or by a single nozzle located concentrically within the tip. At installations where waste gas flow varies, both are used. The internal nozzle provides steam at low waste gas flow rates, and the external jets are used with large waste gas flow rates. Several other special-purpose flare tips are commercially available, one of which is for injecting both steam and air. Typical steam usage ratio varies from 7:1 to 2:1, by weight.

Waste gases to be flared must have a fuel value of at least 7500 to 9300 kilojoules per cubic meter kJ/m^3 (200 to 250 British thermal units per cubic foot [Btu/ft³]) for complete combustion; otherwise fuel must be added. Flares providing supplemental fuel to waste gas are known as fired, or endothermic, flares. In some cases, even flaring waste gases having the necessary heat content will also require supplemental heat. If fuel-bound nitrogen is present, flaring ammonia with a heating value of 13,600 kJ/m³ (365 Btu/ft³) will require higher heat to minimize nitrogen oxides (NO_x) formation.

At many locations, flares normally used to dispose of low-volume continuous emissions are designed to handle large quantities of waste gases that may be intermittently generated during plant emergencies. Flare gas volumes can vary from a few cubic meters per hour during regular operations

up to several thousand cubic meters per hour during major upsets. Flow rates at a refinery could be from 45 to 90 kilograms per hour (kg/hr) (100 - 200 pounds per hour [lb/hr]) for relief valve leakage but could reach a full plant emergency rate of 700 megagrams per hour (Mg/hr) (750 tons/hr). Normal process blowdowns may release 450 to 900 kg/hr (1000 - 2000 lb/hr), and unit maintenance or minor failures may release 25 to 35 Mg/hr (27 - 39 tons/hr). A 40 molecular weight gas typically of 0.012 cubic nanometers per second (nm³/s) (25 standard cubic feet per minute [scfm]) may rise to as high as 115 nm³/s (241,000 scfm). The required flare turndown ratio for this typical case is over 15,000 to 1.

Many flare systems have 2 flares, in parallel or in series. In the former, 1 flare can be shut down for maintenance while the other serves the system. In systems of flares in series, 1 flare, usually a low-level ground flare, is intended to handle regular gas volumes, and the other, an elevated flare, to handle excess gas flows from emergencies.

13.5.2 Emissions

Noise and heat are the most apparent undesirable effects of flare operation. Flares are usually located away from populated areas or are sufficiently isolated, thus minimizing their effects on populations.

Emissions from flaring include carbon particles (soot), unburned hydrocarbons, CO, and other partially burned and altered hydrocarbons. Also emitted are NO_x and, if sulfur-containing material such as hydrogen sulfide or mercaptans is flared, sulfur dioxide (SO₂). The quantities of hydrocarbon emissions generated relate to the degree of combustion. The degree of combustion depends largely on the rate and extent of fuel-air mixing and on the flame temperatures achieved and maintained. Properly operated flares achieve at least 98 percent combustion efficiency in the flare plume, meaning that hydrocarbon and CO emmissions amount to less than 2 percent of hydrocarbons in the gas stream.

The tendency of a fuel to smoke or make soot is influenced by fuel characteristics and by the amount and distribution of oxygen in the combustion zone. For complete combustion, at least the stoichiometric amount of oxygen must be provided in the combustion zone. The theoretical amount of oxygen required increases with the molecular weight of the gas burned. The oxygen supplied as air ranges from 9.6 units of air per unit of methane to 38.3 units of air per unit of pentane, by volume. Air is supplied to the flame as primary air and secondary air. Primary air is mixed with the gas before combustion, whereas secondary air is drawn into the flame. For smokeless combustion, sufficient primary air must be supplied, this varying from about 20 percent of stoichiometric air for a paraffin to about 30 percent for an olefin. If the amount of primary air is insufficient, the gases entering the base of the flame are preheated by the combustion zone, and larger hydrocarbon molecules crack to form hydrogen, unsaturated hydrocarbons, and carbon. The carbon particles may escape further combustion and cool down to form soot or smoke. Olefins and other unsaturated hydrocarbons may polymerize to form larger molecules which crack, in turn forming more carbon.

The fuel characteristics influencing soot formation include the carbon-to-hydrogen (C-to-H) ratio and the molecular structure of the gases to be burned. All hydrocarbons above methane, i. e., those with a C-to-H ratio of greater than 0.33, tend to soot. Branched chain paraffins smoke more readily than corresponding normal isomers. The more highly branched the paraffin, the greater the tendency to smoke. Unsaturated hydrocarbons tend more toward soot formation than do saturated ones. Soot is eliminated by adding steam or air; hence, most industrial flares are steam-assisted and some are air-assisted. Flare gas composition is a critical factor in determining the amount of steam necessary.

Since flares do not lend themselves to conventional emission testing techniques, only a few attempts have been made to characterize flare emissions. Recent EPA tests using propylene as flare gas indicated that efficiencies of 98 percent can be achieved when burning an offgas with at least $11,200 \text{ kJ/m}^3$ (300 Btu/ft³). The tests conducted on steam-assisted flares at velocities as low as 39.6 meters per minute (m/min) (130 ft/min) to 1140 m/min (3750 ft/min), and on air-assisted flares at velocities of 180 m/min (617 ft/min) to 3960 m/min (13,087 ft/min) indicated that variations in incoming gas flow rates have no effect on the combustion efficiency. Flare gases with less than 16,770 kJ/m³ (450 Btu/ft³) do not smoke.

Table 13.5-1 presents flare emission factors, and Table 13.5-2 presents emission composition data obtained from the EPA tests.¹ Crude propylene was used as flare gas during the tests. Methane was a major fraction of hydrocarbons in the flare emissions, and acetylene was the dominant intermediate hydrocarbon species. Many other reports on flares indicate that acetylene is always formed as a stable intermediate product. The acetylene formed in the combustion reactions may react further with hydrocarbon radicals to form polyacetylenes followed by polycyclic hydrocarbons.²

In flaring waste gases containing no nitrogen compounds, NO is formed either by the fixation of atmospheric nitrogen (N) with oxygen (O) or by the reaction between the hydrocarbon radicals present in the combustion products and atmospheric nitrogen, by way of the intermediate stages, HCN, CN, and OCN.² Sulfur compounds contained in a flare gas stream are converted to SO_2 when burned. The amount of SO_2 emitted depends directly on the quantity of sulfur in the flared gases.

Table 13.5-1 (English Units). EMISSION FACTORS FOR FLARE OPERATIONS^a

Component	Emission Factor (lb/10 ⁶ Btu)
Total hydrocarbons ^b	0.14
Carbon monoxide	0.37
Nitrogen oxides	0.068
Soot ^c	0 - 274

EMISSION FACTOR RATING: B

^a Reference 1. Based on tests using crude propylene containing 80% propylene and 20% propane.

^b Measured as methane equivalent.

^c Soot in concentration values: nonsmoking flares, 0 micrograms per liter ($\mu g/L$); lightly smoking flares, 40 $\mu g/L$; average smoking flares, 177 $\mu g/L$; and heavily smoking flares, 274 $\mu g/L$.

	Volume %		
Composition	Average	Range	
Methane	55	14 - 83	
Ethane/Ethylene	8	1 - 14	
Acetylene	5	0.3 - 23	
Propane	7	0 - 16	
Propylene	25	1 - 65	

Table 13.5-2. HYDROCARBON COMPOSITION OF FLARE EMISSION^a

^a Reference 1. The composition presented is an average of a number of test results obtained under the following sets of test conditions: steam-assisted flare using high-Btu-content feed; steamassisted using low-Btu-content feed; air-assisted flare using high-Btu-content feed; and air-assisted flare using low-Btu-content feed. In all tests, "waste" gas was a synthetic gas consisting of a mixture of propylene and propane.

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14. GREENHOUSE GAS BIOGENIC SOURCES

This chapter contains emission factor information for greenhouse gases on those source categories that differ substantially from, and hence cannot be grouped with, the other stationary sources discussed in this publication. Two of these natural emitters, soils and termites, are truly area sources, with their pollutant-generating process(es) dispersed over large land areas. The third source, lightning occurs in the atmosphere and results in the formation of nitrous oxide.

14.1 Emissions From Soils-Greenhouse Gases

14.1.1 General

A good deal of research has been done to estimate emissions of nitrogen oxides (NO_x) from soils. Although numerous measurements have been made, emissions from soils show variability based on a number of factors. Differences in soil type, moisture, temperature, season, crop type, fertilization, and other agricultural practices apparently all play a part in emissions from soils.

Soils emit NO_x through biological and abiological pathways, and emission rates can be categorized either by fertilizer application or land use. Agricultural lands and grasslands are the most significant emission sources within this category. The quantity of NO_x emitted from agricultural land is dependant on fertilizer application and the subsequent microbial denitrification of the soil. Microbial denitrification is a natural process in soil, but denitrification is higher when soil has been fertilized with chemical fertilizers. Both nitrous oxide (N_2O) and nitric oxide (NO) are emitted from this source. Emissions of NO_x from soils are estimated to be as much as 16 percent of the global budget of NO_x in the troposphere, and as much as 8 percent of the NO_x in North America.¹ This section discusses only emissions of N_2O from soils. Refer to reference 2 for information on estimating total NO_x from soils using the EPA's Biogenic Emissions Inventory System (BEIS).

14.1.2 Agricultural Soils

The description of the source and the methodology for estimating emissions and emission factors presented in this section are taken directly from the State Workbook: *Methodologies for Estimating Greenhouse Gas Emissions* and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1994*, prepared by the U.S. Environmental Protection Agency's Office of Policy, Planning and Evaluation (OPPE). A more detailed discussion of the processes and variables affecting N₂O generation from this source can be found in those volumes.^{3,4}

Various agricultural soil management practices contribute to greenhouse gas emissions. The use of synthetic and organic fertilizers adds nitrogen to soils, thereby increasing natural emissions of N_2O . Other agricultural soil management practices such as irrigation, tillage, or the fallowing of land can also affect trace gas fluxes to and from the soil since soils are both a source and a sink for carbon dioxide (CO₂) and carbon monoxide (CO), a sink for methane (CH₄), and a source of N_2O . However, there is much uncertainty about the direction and magnitude of the effects of these other practices, so only the emissions from fertilizer use are included in the method presented here.

Nitrous oxide emissions from commercial fertilizer use can be estimated using the following equation:

 N_2O Emissions = (FC * EC * 44/28)^a

^a EMISSION FACTOR RATING: D.

where:

FC = Fertilizer Consumption (tons N-applied);^b

EC = Emission Coefficient = 0.0117 tons N₂O-N/ton N applied; and

44/28 = The molecular weight ratio of N₂O to N_2O as N (N₂O/N₂O-N).

The emission coefficient of 0.0117 tons N/ton N-applied represents the percent of nitrogen applied as fertilizer that is released into the atmosphere as nitrous oxide. This emission coefficient was obtained from the Agricultural Research Service of the U.S. Department of Agriculture (USDA), which estimated that 1.84 kg N₂O was emitted per 100 kg of nitrogen applied as fertilizer. After applying the appropriate conversion, this is equivalent to 0.0117 tons N₂O-N/ton N-applied.

The total amount of commercial fertilizer consumed in a given state or region is the sum of all synthetic nitrogen, multiple-nutrient, and organic fertilizer applied (measured in mass units of nitrogen). Fertilizer data by type and state can be obtained from the Tennessee Valley Authority's National Fertilizer and Environmental Research Center. In the case of organic fertilizers, such as manure from livestock operations, data may be available from state or local Agricultural Extension offices. There may be instances in which fertilizer consumption is given as the total mass of fertilizer consumed rather than as nitrogen content. In such cases, total mass by fertilizer type may be converted to nitrogen content using the percentages in Table 14.1-1.

Because agricultural activities fluctuate from year to year as a result of economic, climatic, and other variables, it is recommended that an average of 3 years of fertilizer consumption be used to account for extraordinary circumstances.

Example:

For County A, a 3-year average of 16 tons of monoammonium phosphate is applied. As shown in Table 14.1-1, monoammonium phosphate is 11 percent N.

FC = 16 tons fertilizer * 11% N/ton fertilizer = 1.76 tons N

where:

FC = Fertilizer consumption

Emissions are calculated by:

 N_2O Emissions = (1.76 tons N applied) * (0.0117 tons N_2O) * $\frac{44}{28}$

= 0.032 tons N₂O

^b In some instances, state fertilizer consumption data may only be provided by fertilizer type and not aggregated across all types by total N consumed. If this is the case, then analysts must first determine the amount of N consumed for each fertilizer type (using the percentages in Table 14.1-1) and then follow the method presented. To obtain total emissions by state, sum across all types.

Table 14.1-1. NITROGEN CONTENT OF PRINCIPAL FERTILIZER MATERIA
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MATERIAL	% NITROGEN (by wt)
Nitrogen	
Ammonia, Anhydrous	82
Ammonia, Aqua	16-25
Ammonium nitrate	33.5
Ammonium nitrate-limestone mixtures	20.5
Ammonium sulfate	21
Ammonium sulfate-nitrate	26
Calcium cyanamide	21
Calcium nitrate	15
Nitrogen solutions	21-49
Sodium nitrate	16
Urea	46
Urea-form	38
Phosphate	
Basic slag, Open hearth	b
Bone meal	2-4.5
Phosphoric acid	b
Rock phosphate	b
Superphosphate, Normal	b
Superphosphate, Concentrated	b
Superphosphoric acid	b
Potash	b
Potassium chloride (muriate)	b
Potassium magnesium sulfate	b
Potassium sulfate	b
Multiple Nutrient	
Ammoniated superphosphate	3-6
Ammonium phosphate-nitrate	27
Ammonium phosphate-sulfate	13-16
Diammonium phosphate	16-21
Monoammonium phosphate	11
Nitric phosphates	14-22
Nitrate of soda-potash	15
Potassium nitrate	13
Wood ashes	b
Blast furnace slag	b
Dolomite	b
Gypsum	b
Kieserite (emjeo)	b
Limestone	b
Lime-sulfur solution	b
Magnesium sulfate (Epsom salt)	b
Sulfur	b

^a Reference 3.
^b No, or a negligible amount of, nitrogen present.

14.1.3 Other Soils

The amount of N_2O emitted from non-agricultural soils is dependent on the soil's nutrient level and moisture content.⁵ It is believed therefore that soils in tropical regions emit far more N_2O than soils in other terrestrial ecosystems.^{5,6} Because of the variability of soil types and soil moisture levels, some tropical soils emit more N_2O than others.

Global soil N_2O flux measurements were compiled from various sources⁵⁻⁸ and used to delineate soil N_2O emission factors.⁹ Table 14.1-2 presents the mean emission factors developed for 6 ecological regions. These emission factors are based on test data from primarily undisturbed soils.⁹

14.1.4 Uncertainty³

Scientific knowledge regarding nitrous oxide production and emissions from fertilized soils is limited. Significant uncertainties exist regarding the agricultural practices, soil properties, climatic conditions, and biogenic processes that determine how much fertilizer nitrogen various crops absorb, how much remains in soils after fertilizer application, and in what ways the remaining nitrogen evolves into either nitrous oxide or gaseous nitrogen and other nitrogen compounds.

A major difficulty in estimating the magnitude of emissions from this source has been the relative lack of emissions measurement data across a suitably wide variety of controlled conditions, making it difficult to develop statistically valid estimates of emission factors. Previous attempts have been made to develop emission factors for different fertilizer and crop types for state and national emission inventories. However, the accuracy of these emission factors has been questioned. For example, while some studies indicate that N₂O emission rates are higher for ammonium-based fertilizers than for nitrate, other studies show no particular trend in N₂O emissions related to fertilizer types. Therefore, it is possible that fertilizer type is not the most important factor in determining emissions. One study suggests that N₂O emissions from the nitrification of fertilizers may be more closely related to soil properties than to the type of fertilizer applied.

There is consensus, however, as to the fact that numerous natural and management factors influence the biological processes of the soil microorganisms that determine N_2O emissions from nitrogen fertilizer use.

While it is relatively well known how the natural processes individually affect N_2O emissions, it is not well understood how the interaction of the processes affects N_2O emissions. Experiments have shown that in some cases increases in each of the following factors (individually) enhance N_2O emissions: pH, soil temperature, soil moisture, organic carbon content, and oxygen supply. However, the effects on N_2O emissions of soil moisture, organic carbon content, and microbial population together, for example, are not readily predictable.

Management practices may also affect N_2O emissions, although these relationships have not been well quantified. As mentioned, levels of N_2O emissions may be dependent on the type of fertilizer used, although the extent of the effect is not clear, as demonstrated by the wide range of emission coefficients for individual fertilizer types derived in experiments. Although high fertilizer application rates may cause higher N_2O emission rates, the relationship between fertilizer application rate and nitrous oxide emissions is not well understood. Deep placement of fertilizer as an application technique will result in lower N_2O emissions than broadcasting or hand placement. One study found that emissions from fertilizer applied in the fall were higher than emissions from the same fertilizer applied in the spring, indicating that the timing of fertilizer application can affect N_2O emissions. Tillage practices can also affect N_2O emissions. Tilling tends to decrease N_2O emissions; no-till and

Table 14.1-2. EMISSION FACTORS FOR N₂O FROM NON-AGRICULTURAL SOILS^a

EMISSION	FACTOR	RATING:	Ε
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Ecosystem	Emission Factor (lbs N ₂ O/acre/yr) ^b		
Tropical forest	3.692		
Savanna	2.521		
Temperate forest (coniferous)	1.404		
Temperate forest (deciduous)	0.563		
Grassland	1.503		
Shrubs/Woodlands	2.456		

^a Reference 9.

^b To convert lb N₂O/acre/yr to g N₂O/m²/yr, multiply by 0.11208.

use of herbicides may increase N_2O emissions. However, limited research at unique sites under specific conditions has not been able to account for the complex interaction of the factors, making the effects of combinations of factors difficult to predict.

Emissions may also occur from the contamination of surface and ground water due to nutrient leaching and runoff from agricultural systems. However, methods to estimate emissions of N_2O from these sources are not included at this time due to a lack of data and emission coefficients for each contributing activity. Because of the potential relative importance of these N_2O emissions, they should be included in the future as data availability and scientific understanding permit.

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14.2 Termites—Greenhouse Gases

14.2.1 General¹⁻²

Termites inhabit many different ecological regions, but they are concentrated primarily in tropical grasslands and forests. Symbiotic micro-organisms in the digestive tracts of termites (flagellate protozoa in lower termites and bacteria in higher termites) produce methane (CH₄). Estimates of the contribution to the global budget of CH₄ from termites vary widely, from negligible up to 15 percent.

Termite CH_4 emissions estimates vary for several reasons. Researchers have taken different approaches to approximating the number of termites per area for different ecological regions (e.g., cultivated land, temperate grassland, tropical forest) and different species. In addition, the total area per ecological region is not universally agreed upon, and not all of the area in an ecological region is necessarily capable of supporting termites. For example, cultivated land in Europe and Canada is located in a climatic zone where termites cannot survive. Some researchers have tried to estimate the percentage of each region capable of supporting termites while others have conservatively assumed that all of the area of a given ecological region can support termites. Finally, the contributions to atmospheric CH_4 from many other related CH_4 sources and sinks associated with termite populations (i. e., tropical soils) are not well understood.

14.2.2 Emissions³⁻⁴

The only pollutant of concern from termite activity is CH_4 . Emissions of CH_4 from termites can be approximated by an emission factor derived from laboratory test data. Applying these data to field estimates of termite population to obtain a realistic, large-scale value for CH_4 emissions is suspect, but an order-of-magnitude approximation of CH_4 emissions can be made. Termite activity also results in the production of carbon dioxide (CO_2). These CO_2 emissions are part of the regular carbon cycle, and as such should not be included in a greenhouse gas emissions inventory.

Table 14.2-1 reports typical termite densities per ecological region, and Table 14.2-2 provides the CH_4 emission factors for species typical to each ecological region.

A critical data gap currently exists in determining the activity rate for these emission factors (which are given in units of mass of CH_4 per mass of termite). Estimates of termites per acre are given in Table 14.2-1, but converting the number of termites into a usable mass is difficult. If the species of termite is known or can be determined, then the number of termites or the number of termite nests can be converted into a mass of termites. If the species is not known for a particular area, then a typical value must be used that is representative of the appropriate ecological region. Reference 4 provided information on termite density for various North American species, with an average density of 4.86×10^{-6} lb/worker termite.

An example calculation to estimate annual emissions from termites on 5,000 acres of cultivated land is as follows:

5000 acres *
$$\frac{11.38 \times 10^6 \text{ termites}}{\text{acre}} = 5.69 \times 10^{10} \text{ termites}$$

5.69x10¹⁰ termites *
$$\frac{4.86x10^{-6} \text{ lb}}{\text{termite}}$$
 * $\frac{1.8x10^{-3} \text{ lb } \text{CH}_4}{1000 \text{ lb termite}}$ * $\frac{1}{\text{hr}}$ * $\frac{8760 \text{ hr}}{\text{yr}}$
= 4360.39 $\frac{\text{lb } \text{CH}_4}{\text{yr}}$

To convert pounds to kilograms, multiply by 0.454.

Table 14.2-1. TYPICAL TERMITE DENSITIES PER ECOLOGICAL REGION^a

Ecological Region	10 ⁶ Termites per Acre
Tropical wet forest	4.05
Tropical moist forest	18.01
Tropical dry forest	12.80
Temperate	2.43
Wood/shrub land	1.74
Wet savanna	17.81
Dry savanna	3.48
Temperate grassland	8.66
Cultivated land	11.38
Desert scrub	0.93
Clearing and burning	27.62

^a Reference 3.

Table 14.2-2. METHANE EMISSION FACTORS FOR TERMITES^a

Termite Species (Ecological Region)	Methane Emissions (lb CH ₄ /1000 lb termite/hr)
Tropical forest	4.2 E-03
Temperate forest	1.8 E-03
Savanna	8.0 E-03
Temperate grassland	1.8 E-03
Cultivated land	1.8 E-03
Desert scrub	1.0 E-03

EMISSION FACTOR RATING: E

^a References 5 and 6. Reference 7 suggests the following seasonal variation based on studies of the species *Coptotermes lacteus:*

Spring - 22% Summer - 49% Fall - 21% Winter - 8%

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Miscellaneous Sources

14.3 Lightning Emissions-Greenhouse Gases^a

Observations have been made of increased levels of nitrogen oxides (NO_x) , nitric oxide (NO), nitrogen dioxide (NO_2) , and nitrous oxide (N_2O) in the atmosphere after the occurrence and in the proximity of lightning flashes.¹⁻³ Although lightning is thought to be one of the larger natural sources of NO_x , N_2O production by lightning is believed to be substantially less significant, particularly in comparison to anthropogenic sources.⁴⁻⁵ Estimates for global production of N_2O from lightning range from 1.36 E-02 to 9.98 E-02 Tg.⁶ Emission factors for this source are uncertain. Estimates of per-lightning-flash production of NO_x (emission factors) require calculations involving the length of the lightning stroke, the number of strokes per flash, the estimated energy discharge, and the amount of N_2O produced per joule, all of which are under discussion in the literature.

 N_2O emissions from lightning are based on estimates of the molecules produced per joule for each lightning stroke 1.1 E+21 molecules/lightning stroke.⁶

Published estimates for the molecules/joule factors range from 4.3 E+12 to $4.0 \text{ E}+16.^{6}$ Although most researchers use a stroke length of 5 km, stroke length varies. Estimates of the electrical discharge are based on discharge per meter, so the variability of the lightning stroke adds to the emission estimate uncertainty. Other factors that are of significance, but that are not included in this emission factor, are estimates of the number of strokes in a lightning flash (not only are there multiple strokes, but the energy output varies, as does the length of the stroke), and indications that the production of N₂O depends on electrical discharge conditions, not just the amount of the discharge energy.⁷ Estimates for the electrical discharge per lightning flash (as opposed to a lightning stroke) range from 1.0 E+08 joules/flash to 8.0 E+08 joules/flash.⁵

Because the first stroke in a lightning flash will release more energy than subsequent strokes, the energy per flash is estimated by assuming the subsequent strokes release one-quarter the amount of energy released by the first stroke. Hence the total flash energy is assumed to be 1.75 times that of the first return stroke.⁵ The N₂O emission factor for each lightning flash is:

0.14 grams N₂O/flash

The number of lightning flashes within a certain time period and area may be available through the East Coast lightning detection network,⁸ satellite data, or from the lightning strike data archive from the National Lightning Detection Network (GDS) in Tucson, AZ. Several assumptions must be made in order to estimate the total number of lightning flashes from these sources.⁹ It is assumed that not all of the lightning flashes are detected. The East Coast lightning flashes can then be corrected by multiplying the recorded lightning flashes by an efficiency factor of 1.43. It is also assumed that lightning flashes recorded are cloud-to-ground (CG) lightning flashes. Intra-cloud (IC) flashes can be calculated from CG activity, but vary depending on latitude. It is assumed that about four IC flashes occur for every CG flash.

The equation to calculate the number of IC flashes from CG activity is:

^a This section uses only metric units because that is standard in this field.

IC activity = CG activity
$$\left(\frac{10}{\left(1 + \frac{\ell}{30}\right)^2} - 1\right)$$

where:

 ℓ = latitude of the study area in degrees

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TECHNICAL REPORT DATA

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16 ABSTRACT

This document contains emission factors and process information for more than 200 air pollution source categories. These emission factors have been compiled from source test data, material balance studies, and engineering estimates, and they can be used judiciously in making emission estimations for various purposes. When specific source test data are available, they should be preferred over the generalized factors presented in this document.

This Supplement to AP-42 addresses pollutant-generating activity from Bituminous And Subbituminous Coal Combustion, Anthracite Coal Combustion, Fuel Oil Combustion, Natural Gas Combustion, Liquefied Petroleum Gas Combustion, Wood Waste Combustion In Boilers, Lignite Combustion, Bagasse Combustion In Sugar Mills, Residential Fireplaces, Residential Wood Stoves, Waste Oil Combustion, Refuse Combustion, Stationary Gas Turbines For Electricity Generation, Heavy-duty Natural Gas-fired Pipeline Compressor Engines And Turbines, Gasoline And Diesel Industrial Engines, Large Stationary Diesel And All Stationary Dual-fuel Engines, Adipic Acid, Cotton Ginning, Alfalfa Dehydrating, Malt Beverages, Ceramic Products Manufacturing, Electroplating, Wildfires And Prescribed Burning, Emissions From Soils-Greenhouse Gases, Termites-Greenhouse Gases, Lightning Emissions-Greenhouse Gases

17 KEY WORDS AND DOCUMENT ANALYSIS			
B DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c COSATI Field/Group
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APPENDIX A

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MISCELLANEOUS DATA AND CONVERSION FACTORS

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Unit Of Measure	Equiv	alent
grain	0.002	ounces
gram	0.04	ounces
ounce	28.35	grams
kilogram	2.21	pounds
pound	0.45	kilograms
pound (troy)	12	ounces
ton (short)	2000	pounds
ton (long)	2240	pounds
ton (metric)	2200	pounds
ton (shipping)	40	feet ³
centimeter	0.39	inches
inch	2.54	centimeters
foot	30.48	centimeters
meter	1.09	yards
yard	0.91	meters
mile	1.61	kilometers
centimeter ²	0.16	inches ²
inch ²	6.45	centimeters ²
foot ²	0.09	meters ²
meter ²	1.2	yards ²
yard ²	0.84	meters ²
mile ²	2.59	kilometers ²
centimeter ³	0.061	inches ³
inch ³	16.39	centimeters ³
foot ³	283.17	centimeters ³
foot ³	1728	inches ³

SOME USEFUL WEIGHTS AND MEASURES

Unit Of Measure	Equivalent
meter ³	1.31 yeads ³
yard ³	0.77 meters ³
cord	128 feet ³
cord	4 meters ³
peck	8 quarts
bushel (dry)	4 pecks
bushel	2150.4 inches ³
gallon (U. S.)	231 inches ³
barrel	31.5 gallons
hogshead	2 barrels
township	36 miles ²
hectare	2.5 acres

SOME USEFUL WEIGHTS AND MEASURES (cont.)

MISCELLANEOUS DATA

One cubic foot of anthracite coal weighs about 53 pounds.

One cubic foot of bituminous coal weighs from 47 to 50 pounds.

One ton of coal is equivalent to two cords of wood for steam purposes.

A gallon of water (U. S. Standard) weighs 8.33 pounds and contains 231 cubic inches.

There are 9 square feet of heating surface to each square foot of grate surface.

A cubic foot of water contains 7.5 gallons and 1728 cubic inches, and weighs 62.5 lbs.

Each nominal horsepower of a boiler requires 30 to 35 pounds of water per hour.

A horsepower is equivalent to raising 33,000 pounds one foot per minute, or 550 pounds one foot per second.

To find the pressure in pounds per square inch of a column of water, multiply the height of the column in feet by 0.434.

	Heating Value		Sulfur	Ach
Type Of Fuel	kcal	Btu	% (by weight)	% (by weight)
Solid Fuels				
Bituminous Coal	7,200/kg	13,000/lb	0.6-5.4	4-20
Anthracite Coal	6,810/kg	12 ,30 0/lb	0.5-1.0	7.0-16.0
Lignite (@ 35% moisture)	3,990/kg	7,200/lb	0.7	6.2
Wood (@ 40% moisture)	2,880/kg	5,200/lb	Ν	1-3
Bagasse (@ 50% moisture)	2,220/kg	4,000/lb	Ν	1-2
Bark (@ 50% moisture)	2,492/kg	4,500/lb	Ν	1-3 ^b
Coke, Byproduct	7,380/kg	13,300/lb	0.5-1.0	0.5-5.0
Liquid Fuels				
Residual Oil	$9.98 \times 10^{6}/m^{3}$	150,000/gal	0.5-4.0	0.05-0.1
Distillate Oil	9.30 x $10^{6}/m^{3}$	140,000/gal	0.2-1.0	Ν
Diesel	$9.12 \times 10^6/m^3$	137,000/gal	0.4	Ν
Gasoline	$8.62 \times 10^6/m^3$	130,000/gal	0.03-0.04	Ν
Kerosene	$8.32 \times 10^6/m^3$	135,000/gal	0.02-0.05	Ν
Liquid Petroleum Gas	$6.25 \times 10^{6}/m^{3}$	94,000/gal	N	Ν
Gaseous Fuels				
Natural Gas	9,341/m ³	1,050/SCF	N	Ν
Coke Oven Gas	5,249/m ³	590/SCF	0.5-2.0	Ν
Blast Furnace Gas	890/m ³	100/SCF	N	Ν

TYPICAL PARAMETERS OF VARIOUS FUELS^a

^a N = negligible.
 ^b Ash content may be considerably higher when sand, dirt, etc., are present.

Type Of Fuel	kcal	Btu (gross)
Solid fuels		
Bituminous coal	(5.8 to 7.8) x 10 ⁶ /Mg	(21.0 to 28.0) x 10 ⁶ /ton
Anthracite coal	7.03 x 10 ⁶ /Mg	25.3 x 10 ⁶ /ton
Lignite	4.45 x 10 ⁶ /Mg	16.0 x 10 ⁶ /ton
Wood	$1.47 \times 10^{6}/m^{3}$	$21.0 \times 10^{6}/cord$
Liquid fuels		
Residual fuel oil	10 x 10 ³ /liter	6.3 x 10 ⁶ /bbl
Distillate fuel oil	9.35 x 10 ³ /liter	5.9 x 10 ⁶ /bbl
Gaseous fuels		
Natural gas	9,350/m ³	1,050/ft ³
Liquefied petroleum gas		
Butane	6,480/liter	97,400/gal
Propane	6,030/liter	90,500/gal

THERMAL EQUIVALENTS FOR VARIOUS FUELS

WEIGHTS OF SELECTED SUBSTANCES

Type Of Substance	g/liter	lb/gal
Asphalt	1030	8.57
Butane, liquid at 60°F	579	4.84
Crude oil	850	7.08
Distillate oil	845	7.05
Gasoline	739	6.17
Propane, liquid at 60°F	507	4.24
Residual oil	944	7.88
Water	1000	8.4

DENSITIES OF SELECTED SUBSTANCES

Substance	Density	
Fuels		
Crude Oil	874 kg/m ³	7.3 lb/gal
Residual Oil	944 kg/m ³	7.88 lb/gal
Distillate Oil	845 kg/m ³	7.05 lb/gal
Gasoline	739 kg/m ³	6.17 lb/gal
Natural Gas	673 kg/m ³	1 lb/23.8 ft ³
Butane	579 kg/m ³	4.84 lb/gal (liquid)
Propane	507 kg/m ³	4.24 lb/gal (liquid)
Wood (Air dried)		
Elm	561 kg/m ³	35 lb/ft ³
Fir, Douglas	513 kg/m ³	32 lb/ft ³
Fir, Balsam	400 kg/m ³	25 lb/ft^3
Hemlock	465 kg/m ³	29 lb/ft ³
Hickory	769 kg/m ³	48 lb/ft ³
Maple, Sugar	689 kg/m ³	43 lb/ft ³
Maple, White	529 kg/m ³	33 lb/ft ³
Oak, Red	673 kg/m ³	42 lb/ft ³
Oak, White	769 kg/m ³	48 lb/ft ³
Pine, Southern	641 kg/m ³	40 lb/ft ³
Agricultural Products		
Corn	25.4 kg/bu	56 lb/bu
Milo	25.4 kg/bu	56 lb/bu
Oats	14.5 kg/bu	32 lb/bu
Barley	21.8 kg/bu	48 lb/bu
Wheat	27.2 kg/bu	60 lb/bu
Cotton	226 kg/bale	500 lb/bale
Mineral Products		
Brick	2.95 kg/brick	6.5 lb/brick
Cement	170 kg/bbl	375 lb/bbl
Cement	1483 kg/m ³	2500 lb/yd ³

Substance	Density	
Concrete	2373 kg/m ³	4000 lb/yd ³
Glass, Common	2595 kg/m ³	162 lb/ft ³
Gravel, Dry Packed	1600 - 1920 kg/m ³	100 - 120 lb/ft ³
Gravel, Wet	2020 kg/m ³	126 lb/ft ³
Gypsum, Calcined	880 - 960 kg/m ³	55 - 60 lb/ft ³
Lime, Pebble	850 - 1025 kg/m ³	53 - 64 lb/ft ³
Sand, Gravel (Dry, loose)	1440 - 1680 kg/m ³	90 - 105 lb/ft ³

DENSITIES OF SELECTED SUBSTANCES (cont.).

CONVERSION FACTORS

The table of conversion factors on the following pages contains factors for converting English to metric units and metric to English units as well as factors to manipulate units within the same system. The factors are arranged alphabetically by unit within the following property groups.

- Area
- Density
- Energy
- Force
- Length
- Mass
- Pressure
- Velocity
- Volume
- Volumetric Rate

To convert a number from one unit to another:

- 1. Locate the unit in which the number is currently expressed in the left-hand column of the table;
- 2. Find the desired unit in the center column; and
- 3. Multiply the number by the corresponding conversion factor in the right-hand column.

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CONVERSION FACTORS^a

To Convert From	То	Multiply By
Area		
Acres	Sq feet	4.356 x 10 ⁴
Acres	Sq kilometers	4.0469 x 10 ⁻³
Acres	Sq meters	4.0469×10^3
Acres	Sq miles (statute)	1.5625 x 10 ⁻³
Acres	Sq yards	4.84 x 10 ³
Sq feet	Acres	2.2957 x 10 ⁻⁵
Sq feet	Sq cm	929.03
Sq feet	Sq inches	144.0
Sq feet	Sq meters	0.092903
Sq feet	Sq miles	3.587 x 10 ⁻⁸
Sq feet	Sq yards	0.111111
Sq inches	Sq feet	6.9444 x 10 ⁻³
Sq inches	Sq meters	6.4516 x 10 ⁻⁴
Sq inches	Sq mm	645.16
Sq kilometers	Acres	247.1
Sq kilometers	Sq feet	1.0764 x 10 ⁷
Sq kilometers	Sq meters	1.0 x 10 ⁶
Sq kilometers	Sq miles	0.386102
Sq kilometers	Sq yards	1.196 x 10 ⁶
Sq meters	Sq cm	$1.0 \ge 10^4$
Sq meters	Sq feet	10.764
Sq meters	Sq inches	1.55×10^3
Sq meters	Sq kilometers	1.0 x 10 ⁻⁶
Sq meters	Sq miles	3.861 x 10 ⁻⁷
Sq meters	Sq mm	1.0 x 10 ⁶
Sq meters	Sq yards	1.196
Sq miles	Acres	640.0
Sq miles	Sq feet	2.7878 x 10 ⁷
Sq miles	Sq kilometers	2.590

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To Convert From	То	Multiply By
Sq miles	Sq meters	2.59 x 10 ⁶
Sq miles	Sq yards	3.0976 x 10 ⁶
Sq yards	Acres	2.0661 x 10 ⁻⁴
Sq yards	Sq cm	8.3613 x 10 ³
Sq yards	Sq ft	9.0
Sq yards	Sq inches	1.296 x 10 ³
Sq yards	Sq meters	0.83613
Sq yards	Sq miles	3.2283 x 10 ⁻⁷
Density		
Dynes/cu cm	Grams/cu cm	1.0197 x 10 ⁻³
Grains/cu foot	Grams/cu meter	2.28835
Grams/cu cm	Dynes/cu cm	980.665
Grams/cu cm	Grains/milliliter	15.433
Grams/cu cm	Grams/milliliter	1.0
Grams/cu cm	Pounds/cu inch	1.162
Grams/cu cm	Pounds/cu foot	62.428
Grams/cu cm	Pounds/cu inch	0.036127
Grams/cu cm	Pounds/gal (Brit.)	10.022
Grams/cu cm	Pounds/gal (U. S., dry)	9.7111
Grams/cu cm	Pounds/gal (U. S., liq.)	8.3454
Grams/cu meter	Grains/cu foot	0.4370
Grams/liter	Pounds/gal (U. S.)	8.345 x 10 ⁻³
Kilograms/cu meter	Grams/cu cm	0.001
Kilograms/cu meter	Pounds/cu ft	0.0624
Kilograms/cu meter	Pounds/cu in	3.613 x 10 ⁻⁵
Pounds/cu foot	Grams/cu cm	0.016018
Pounds/cu foot	kg/cu meter	16.018
Pounds/cu inch	Grams/cu cm	27.68
Pounds/cu inch	Grams/liter	27.681
Pounds/cu inch	kg/cu meter	2.768 x 10 ⁴

To Convert From	То	Multiply By
Pounds/gal (U. S., liq.)	Grams/cu cm	0.1198
Pounds/gal (U. S., liq.)	Pounds/cu ft	7.4805
Energy		
Btu	Cal. gm (IST.)	251.83
Btu	Ergs	1.05435 x 10 ¹⁰
Btu	Foot-pounds	777.65
Btu	Hp-hours	3.9275 x 10 ⁻⁴
Btu	Joules (Int.)	1054.2
Btu	kg-meters	107.51
Btu	kW-hours (Int.)	2.9283 x 10 ⁻⁴
Btu/hr	Cal. kg/hr	0.252
Btu/hr	Ergs/sec	2.929 x 10 ⁶
Btu/hr	Foot-pounds/hr	777.65
Btu/hr	Horsepower (mechanical)	3.9275 x 10 ⁻⁴
Btu/hr	Horsepower (boiler)	2.9856 x 10 ⁻⁵
Btu/hr	Horsepower (electric)	3.926 x 10 ⁻⁴
Btu/hr	Horsepower (metric)	3.982 x 10 ⁻⁴
Btu/hr	Kilowatts	2.929 x 10 ⁻⁴
Btu/lb	Foot-pounds/lb	777.65
Btu/lb	Hp-hr/lb	3.9275 x 10 ⁻⁴
Btu/lb	Joules/gram	2.3244
Calories, kg (mean)	Btu (IST.)	3.9714
Calories, kg (mean)	Ergs	4.190 x 10 ¹⁰
Calories, kg (mean)	Foot-pounds	3.0904×10^3
Calories, kg (mean)	Hp-hours	1.561 x 10 ⁻³
Calories, kg (mean)	Joules	4.190 x 10 ³
Calories, kg (mean)	kg-meters	427.26
Calories, kg (mean)	kW-hours (Int.)	1.1637 x 10 ⁻³
Ergs	Btu	9.4845 x 10 ⁻¹¹
Ergs	Foot-poundals	2.373 x 10 ⁻⁶

To Convert From	То	Multiply By
Ergs	Foot-pounds	7.3756 x 10 ⁻⁸
Ergs	Joules (Int.)	9.99835 x 10 ⁻⁸
Ergs	kW-hours	2.7778 x 10 ⁻¹⁴
Ergs	kg-meters	1.0197 x 10 ⁻⁸
Foot-pounds	Btu (IST.)	1.2851 x 10 ⁻³
Foot-pounds	Cal. kg (IST.)	3.2384 x 10 ⁻⁴
Foot-pounds	Ergs	1.3558 x 10 ⁷
Foot-pounds	Foot-poundals	32.174
Foot-pounds	Hp-hours	5.0505 x 10 ⁻⁷
Foot-pounds	Joules	1.3558
Foot-pounds	kg-meters	0.138255
Foot-pounds	kW-hours (Int.)	3.76554 x 10 ⁻⁷
Foot-pounds	Newton-meters	1.3558
Foot-pounds/hr	Btu/min	2.1432 x 10 ⁻⁵
Foot-pounds/hr	Ergs/min	2.2597 x 10 ⁵
Foot-pounds/hr	Horsepower (mechanical)	5.0505 x 10 ⁻⁷
Foot-pounds/hr	Horsepower (metric)	5.121 x 10 ⁻⁷
Foot-pounds/hr	Kilowatts	3.766 x 10 ⁻⁷
Horsepower (mechanical)	Btu (mean)/hr	2.5425 x 10 ³
Horsepower (mechanical)	Ergs/sec	7.457 x 10 ⁹
Horsepower (mechanical)	Foot-pounds/hr	1.980 x 10 ⁶
Horsepower (mechanical)	Horsepower (boiler)	0.07602
Horsepower (mechanical)	Horsepower (electric)	0.9996
Horsepower (mechanical)	Horsepower (metric)	1.0139
Horsepower (mechanical)	Joules/sec	745.70
Horsepower (mechanical)	Kilowatts (Int.)	0.74558
Horsepower (boiler)	Btu (mean)/hr	3.3446 x 10 ⁴
Horsepower (boiler)	Ergs/sec	9.8095 x 10 ¹⁰
Horsepower (boiler)	Foot-pounds/min	4.341 x 10 ⁵
Horsepower (boiler)	Horsepower (mechanical)	13.155

To Convert From	То	Multiply By
Horsepower (boiler)	Horsepower (electric)	13.15
Horsepower (boiler)	Horsepower (metric)	13.337
Horsepower (boiler)	Joules/sec	9.8095 x 10 ³
Horsepower (boiler)	Kilowatts	9.8095
Horsepower (electric)	Btu (mean)/hr	2.5435 x 10 ³
Horsepower (electric)	Cal. kg/hr	641.87
Horsepower (electric)	Ergs/sec	7.46 x 10 ⁹
Horsepower (electric)	Foot-pounds/min	3.3013 x 10 ⁴
Horsepower (electric)	Horsepower (boiler)	0.07605
Horsepower (electric)	Horsepower (metric)	1.0143
Horsepower (electric)	Joules/sec	746.0
Horsepower (electric)	Kilowatts	0.746
Horsepower (metric)	Btu (mean)/hr	2.5077 x 10 ³
Horsepower (metric)	Ergs/sec	7.355 x 10 ⁹
Horsepower (metric)	Foot-pounds/min	3.255×10^4
Horsepower (metric)	Horsepower (mechanical)	0.98632
Horsepower (metric)	Horsepower (boiler)	0.07498
Horsepower (metric)	Horsepower (electric)	0.9859
Horsepower (metric)	kg-meters/sec	75.0
Horsepower (metric)	Kilowatts	0.7355
Horsepower-hours	Btu (mean)	2.5425 x 10 ³
Horsepower-hours	Foot-pounds	1.98 x 10 ⁶
Horsepower-hours	Joules	2.6845 x 10 ⁶
Horsepower-hours	kg-meters	2.73745 x 10 ⁵
Horsepower-hours	kW-hours	0.7457
Joules (Int.)	Btu (IST.)	9.4799 x 10 ⁻⁴
Joules (Int.)	Ergs	1.0002×10^7
Joules (Int.)	Foot-poundals	12.734
Joules (Int.)	Foot-pounds	0.73768
Joules (Int.)	kW-hours	2.778 x 10 ⁻⁷

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To Convert From	То	Multiply By
Joules (Int.)/sec	Btu (mean)/min	0.05683
Joules (Int.)/sec	Cal. kg/min	0.01434
Joules (Int.)/sec	Horsepower	1.341 x 10 ⁻³
Kilogram-meters	Btu (mean)	9.2878 x 10 ⁻³
Kilogram-meters	Cal. kg (mean)	2.3405 x 10 ⁻³
Kilogram-meters	Ergs	9.80665 x 10 ⁷
Kilogram-meters	Foot-poundals	232.715
Kilogram-meters	Foot-pounds	7.233
Kilogram-meters	Hp-hours	3.653 x 10 ⁻⁶
Kilogram-meters	Joules (Int.)	9.805
Kilogram-meters	kW-hours	2.724 x 10 ⁻⁶
Kilogram-meters/sec	Watts	9.80665
Kilowatts (Int.)	Btu (IST.)/hr	3.413 x 10 ³
Kilowatts (Int.)	Cal. kg (IST.)/hr	860.0
Kilowatts (Int.)	Ergs/sec	1.0002 x 10 ¹⁰
Kilowatts (Int.)	Foot-poundals/min	1.424 x 10 ⁶
Kilowatts (Int.)	Foot-pounds/min	4.4261 x 10 ⁴
Kilowatts (Int.)	Horsepower (mechanical)	1.341
Kilowatts (Int.)	Horsepower (boiler)	0.10196
Kilowatts (Int.)	Horsepower (electric)	1.3407
Kilowatts (Int.)	Horsepower (metric)	1.3599
Kilowatts (Int.)	Joules (Int.)/hr	3.6 x 10 ⁶
Kilowatts (Int.)	kg-meters/hr	3.6716 x 10 ⁵
Kilowatt-hours (Int.)	Btu (mean)	3.41 x 10 ³
Kilowatt-hours (Int.)	Foot-pounds	2.6557 x 10 ⁶
Kilowatt-hours (Int.)	Hp-hours	1.341
Kilowatt-hours (Int.)	Joules (Int.)	3.6 x 10 ⁶
Kilowatt-hours (Int.)	kg-meters	3.6716 x 10 ⁵
Newton-meters	Gram-cm	1.01972 x 10 ⁴
Newton-meters	kg-meters	0.101972

To Convert From То Multiply By Newton-meters Pound-feet 0.73756 Force 1.0 x 10⁻⁵ Newtons Dynes 7.233 x 10⁻⁵ Dynes Poundals Pounds 2.248 x 10⁻⁶ Dynes 1.0 x 10⁻⁵ Newtons Dynes Pounds (avdp.) 0.22481 Newtons 1.383×10^4 Poundals Dynes 0.1383 Poundals Newtons **Poundals** Pounds (avdp.) 0.03108 4.448 x 10⁵ Pounds (avdp.) Dynes 4.448 Newtons Pounds (avdp.) Pounds (avdp.) Poundals 32.174 Length 30.48 Centimeters Feet 12 Feet Inches 3.048 x 10⁻⁴ Kilometers Feet 0.3048 Feet Meters 1.894 x 10⁻⁴ Feet Miles (statute) 2.540 Inches Centimeters 0.08333 Inches Feet 2.54 x 10⁻⁵ Kilometers Inches Meters 0.0254 Inches 3.2808×10^3 Feet Kilometers 1000 Meters Kilometers Miles (statute) 0.62137 Kilometers 1.0936×10^3 Yards Kilometers 3.2808 Feet Meters 39.370 Inches Meters 1.0×10^4 Angstrom units Micrometers

To Convert From	То	Multiply By
Micrometers	Centimeters	1.0 x 10 ⁻³
Micrometers	Feet	3.2808 x 10 ⁻⁶
Micrometers	Inches	3.9370 x 10 ⁻⁵
Micrometers	Meters	1.0 x 10 ⁻⁶
Micrometers	Millimeters	0.001
Micrometers	Nanometers	1000
Miles (statute)	Feet	5280
Miles (statute)	Kilometers	1.6093
Miles (statute)	Meters	1.6093 x 10 ³
Miles (statute)	Yards	1760
Millimeters	Angstrom units	1.0×10^7
Millimeters	Centimeters	0.1
Millimeters	Inches	0.03937
Millimeters	Meters	0.001
Millimeters	Micrometers	1000
Millimeters	Mils	39.37
Nanometers	Angstrom units	10
Nanometers	Centimeters	1.0 x 10 ⁻⁷
Nanometers	Inches	3.937 x 10 ⁻⁸
Nanometers	Micrometers	0.001
Nanometers	Millimeters	1.0 x 10 ⁻⁶
Yards	Centimeters	91.44
Yards	Meters	0.9144
Mass		
Grains	Grams	0.064799
Grains	Milligrams	64.799
Grains	Pounds (apoth. or troy)	1.7361 x 10 ⁻⁴
Grains	Pounds (avdp.)	1.4286 x 10 ⁻⁴
Grains	Tons (metric)	6.4799 x 10 ⁻⁸
Grams	Dynes	980.67

To Convert From	То	Multiply By
Grams	Grains	15.432
Grams	Kilograms	0.001
Grams	Micrograms	1 x 10 ⁶
Grams	Pounds (avdp.)	2.205 x 10 ⁻³
Grams	Tons, metric (megagrams)	1 x 10 ⁻⁶
Kilograms	Grains	1.5432 x 10 ⁴
Kilograms	Poundals	70.932
Kilograms	Pounds (apoth. or troy)	2.679
Kilograms	Pounds (avdp.)	2.2046
Kilograms	Tons (long)	9.842 x 10 ⁻⁴
Kilograms	Tons (metric)	0.001
Kilograms	Tons (short)	1.1023 x 10 ⁻³
Megagrams	Tons (metric)	1.0
Milligrams	Grains	0.01543
Milligrams	Grams	1.0 x 10 ⁻³
Milligrams	Ounces (apoth. or troy)	3.215 x 10 ⁻⁵
Milligrams	Ounces (avdp.)	3.527 x 10 ⁻⁵
Milligrams	Pounds (apoth. or troy)	2.679 x 10 ⁻⁶
Milligrams	Pounds (avdp.)	2.2046 x 10 ⁻⁶
Ounces (apoth. or troy)	Grains	480
Ounces (apoth. or troy)	Grams	31.103
Ounces (apoth. or troy)	Ounces (avdp.)	1.097
Ounces (avdp.)	Grains	437.5
Ounces (avdp.)	Grams	28.350
Ounces (avdp.)	Ounces (apoth. or troy)	0.9115
Ounces (avdp.)	Pounds (apoth. or troy)	0.075955
Ounces (avdp.)	Pounds (avdp.)	0.0625
Pounds (avdp.)	Poundals	32.174
Pounds (avdp.)	Pounds (apoth. or troy)	1.2153
Pounds (avdp.)	Tons (long)	4.4643 x 10 ⁻⁴

To Convert From	То	Multiply By
Pounds (avdp.)	Tons (metric)	4.5359 x 10 ⁻⁴
Pounds (avdp.)	Tons (short)	5.0 x 10 ⁻⁴
Pounds (avdp.)	Grains	7000
Pounds (avdp.)	Grams	453.59
Pounds (avdp.)	Ounces (apoth. or troy)	14.583
Pounds (avdp.)	Ounces (avdp.)	16
Tons (long)	Kilograms	1.016 x 10 ³
Tons (long)	Pounds (apoth. or troy)	2.722 x 10 ³
Tons (long)	Pounds (avdp.)	2.240 x 10 ³
Tons (long)	Tons (metric)	1.016
Tons (long)	Tons (short)	1.12
Tons (metric)	Grams	1.0 x 10 ⁶
Tons (metric)	Megagrams	1.0
Tons (metric)	Pounds (apoth. or troy)	2.6792 x 10 ³
Tons (metric)	Pounds (avdp.)	2.2046 x 10 ³
Tons (metric)	Tons (long)	0.9842
Tons (metric)	Tons (short)	1.1023
Tons (short)	Kilograms	907.18
Tons (short)	Pounds (apoth. or troy)	2.4301 x 10 ³
Tons (short)	Pounds (avdp.)	2000
Tons (short)	Tons (long)	0.8929
Tons (short)	Tons (metric)	0.9072
Pressure		
Atmospheres	cm of H_2O (4°C)	1.033 x 10 ³
Atmospheres	Ft of H ₂ O (39.2°F)	33.8995
Atmospheres	In. of Hg (32°F)	29.9213
Atmospheres	kg/sq cm	1.033
Atmospheres	mm of Hg (0°C)	760
Atmospheres	Pounds/sq inch	14.696
Inches of Hg (60°F)	Atmospheres	0.03333

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To Convert From	То	Multiply By
Inches of Hg (60°F)	Grams/sq cm	34.434
Inches of Hg (60°F)	mm of Hg (60°F)	25.4
Inches of Hg (60°F)	Pounds/sq ft	70.527
Inches of H ₂ O (4°C)	Atmospheres	2.458 x 10 ⁻³
Inches of H ₂ O (4°C)	In. of Hg (32°F)	0.07355
Inches of H ₂ O (4°C)	kg/sq meter	25.399
Inches of H ₂ O (4°C)	Pounds/sq ft	5.2022
Inches of H ₂ O (4°C)	Pounds/sq inch	0.036126
Kilograms/sq cm	Atmospheres	0.96784
Kilograms/sq cm	cm of Hg (0°C)	73.556
Kilograms/sq cm	Ft of H ₂ O (39.2°F)	32.809
Kilograms/sq cm	In. of Hg (32°F)	28.959
Kilograms/sq cm	Pounds/sq inch	14.223
Millimeters of Hg (0°C)	Atmospheres	1.3158 x 10 ⁻³
Millimeters of Hg (0°C)	Grams/sq cm	1.3595
Millimeters of Hg (0°C)	Pounds/sq inch	0.019337
Pounds/sq inch	Atmospheres	0.06805
Pounds/sq inch	cm of Hg (0°C)	5.1715
Pounds/sq inch	cm of H_2O (4°C)	70.309
Pounds/sq inch	In. of Hg (32°F)	2.036
Pounds/sq inch	In. of H ₂ O (39.2°F)	27.681
Pounds/sq inch	kg/sq cm	0.07031
Pounds/sq inch	mm of Hg (0°C)	51.715
Velocity		
Centimeters/sec	Feet/min	1.9685
Centimeters/sec	Feet/sec	0.0328
Centimeters/sec	Kilometers/hr	0.036
Centimeters/sec	Meters/min	0.6
Centimeters/sec	Miles/hr	0.02237

To Convert From	То	Multiply By
Feet/minute	cm/sec	0.508
Feet/minute	Kilometers/hr	0.01829
Feet/minute	Meters/min	0.3048
Feet/minute	Meters/sec	5.08 x 10 ⁻³
Feet/minute	Miles/hr	0.01136
Feet/sec	cm/sec	30.48
Feet/sec	Kilometers/hr	1.0973
Feet/sec	Meters/min	18.288
Feet/sec	Miles/hr	0.6818
Kilometers/hr	cm/sec	27.778
Kilometers/hr	Feet/hr	3.2808 x 10 ³
Kilometers/hr	Feet/min	54.681
Kilometers/hr	Meters/sec	0.27778
Kilometers/hr	Miles (statute)/hr	0.62137
Meters/min	cm/sec	1.6667
Meters/min	Feet/min	3.2808
Meters/min	Feet/sec	0.05468
Meters/min	Kilometers/hr	0.06
Miles/hr	cm/sec	44.704
Miles/hr	Feet/hr	5280
Miles/hr	Feet/min	88
Miles/hr	Feet/sec	1.4667
Miles/hr	Kilometers/hr	1.6093
Miles/hr	Meters/min	26.822
Volume		
Barrels (petroleum, U. S.)	Cu feet	5.6146
Barrels (petroleum, U. S.)	Gallons (U. S.)	42
Barrels (petroleum, U. S.)	Liters	158.98
Barrels (U. S., liq.)	Cu feet	4.2109
Barrels (U. S., liq.)	Cu inches	7.2765 x 10 ³

To Convert From	То	Multiply By
Barrels (U. S., liq.)	Cu meters	0.1192
Barrels (U. S., liq.)	Gallons (U. S., liq.)	31.5
Barrels (U. S., liq.)	Liters	119.24
Cubic centimeters	Cu feet	3.5315 x 10 ⁻⁵
Cubic centimeters	Cu inches	0.06102
Cubic centimeters	Cu meters	1.0 x 10 ⁻⁶
Cubic centimeters	Cu yards	1.308 x 10 ⁻⁶
Cubic centimeters	Gallons (U. S., liq.)	2.642 x 10 ⁻⁴
Cubic centimeters	Quarts (U. S., liq.)	1.0567 x 10 ⁻³
Cubic feet	Cu centimeters	2.8317 x 10 ⁴
Cubic feet	Cu meters	0.028317
Cubic feet	Gallons (U. S., liq.)	7.4805
Cubic feet	Liters	28.317
Cubic inches	Cu cm	16.387
Cubic inches	Cu feet	5.787 x 10 ⁻⁴
Cubic inches	Cu meters	1.6387 x 10 ⁻⁵
Cubic inches	Cu yards	2.1433 x 10 ⁻⁵
Cubic inches	Gallons (U. S., liq.)	4.329 x 10 ⁻³
Cubic inches	Liters	0.01639
Cubic inches	Quarts (U. S., liq.)	0.01732
Cubic meters	Barrels (U. S., liq.)	8.3864
Cubic meters	Cu cm	1.0 x 10 ⁶
Cubic meters	Cu feet	35.315
Cubic meters	Cu inches	6.1024 x 10 ⁴
Cubic meters	Cu yards	1.308
Cubic meters	Gallons (U. S., liq.)	264.17
Cubic meters	Liters	1000
Cubic yards	Bushels (Brit.)	21.022
Cubic yards	Bushels (U. S.)	21.696
Cubic yards	Cu cm	7.6455 x 10 ⁵

EMISSION FACTORS

To Convert From	То	Multiply By
Cubic yards	Cu feet	27
Cubic yards	Cu inches	4.6656 x 10 ⁴
Cubic yards	Cu meters	0.76455
Cubic yards	Gallons	168.18
Cubic yards	Gallons	173.57
Cubic yards	Gallons	201.97
Cubic yards	Liters	764.55
Cubic yards	Quarts	672.71
Cubic yards	Quarts	694.28
Cubic yards	Quarts	807.90
Gallons (U. S., liq.)	Barrels (U. S., liq.)	0.03175
Gallons (U. S., liq.)	Barrels (petroleum, U. S.)	0.02381
Gallons (U. S., liq.)	Bushels (U. S.)	0.10742
Gallons (U. S., liq.)	Cu centimeters	3.7854 x 10 ³
Gallons (U. S., liq.)	Cu feet	0.13368
Gallons (U. S., liq.)	Cu inches	231
Gallons (U. S., liq.)	Cu meters	3.7854 x 10 ⁻³
Gallons (U. S., liq.)	Cu yards	4.951 x 10 ⁻³
Gallons (U. S., liq.)	Gallons (wine)	1.0
Gallons (U. S., liq.)	Liters	3.7854
Gallons (U. S., liq.)	Ounces (U. S., fluid)	128.0
Gallons (U. S., liq.)	Pints (U. S., liq.)	8.0
Gallons (U. S., liq.)	Quarts (U. S., liq.)	4.0
Liters	Cu centimeters	1000
Liters	Cu feet	0.035315
Liters	Cu inches	61.024
Liters	Cu meters	0.001
Liters	Gallons (U. S., liq.)	0.2642
Liters	Ounces (U. S., fluid)	33.814

To Convert From	То	Multiply By
Volumetric Rate		
Cu ft/min	Cu cm/sec	471.95
Cu ft/min	Cu ft /hr	60. 0
Cu ft/min	Gal (U. S.)/min	7.4805
Cu ft/min	Liters/sec	0.47193
Cu meters/min	Gal (U. S.)/min	264.17
Cu meters/min	Liters/min	999.97
Gallons (U. S.)/hr	Cu ft/hr	0.13368
Gallons (U. S.)/hr	Cu meters/min	6.309 x 10 ⁻⁵
Gallons (U. S.)/hr	Cu yd/min	8.2519 x 10 ⁻⁵
Gallons (U. S.)/hr	Liters/hr	3.7854
Liters/min	Cu ft/min	0.0353
Liters/min	Gal (U. S., liq.)/min	0.2642

^a Where appropriate, the conversion factors appearing in this table have been rounded to four to six significant figures for ease in use. The accuracy of these numbers is considered suitable for use with emissions data; if a more accurate number is required, tables containing exact factors should be consulted.

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS

To Convert From	То	Multiply By
Milligrams/cu m	Grams/cu ft	283.2 x 10 ⁻⁶
	Grams/cu m	0.001
	Micrograms/cu m	1000.0
	Micrograms/cu ft	28.32
	Pounds/1000 cu ft	62.43 x 10 ⁻⁶
Grams/cu ft	Milligrams/cu m	35.3145 x 10 ³
	Grams/cu m	35.314
	Micrograms/cu m	35.314 x 10 ⁶
	Micrograms/cu ft	1.0 x 10 ⁶
	Pounds/1000 cu ft	2.2046
Grams/cu m	Milligrams/cu m	1000.0
	Grams/cu ft	0.02832
	Micrograms/cu m	1.0 x 10 ⁶
	Micrograms/cu ft	28.317 x 10 ³
	Pounds/1000 cu ft	0.06243
Micrograms/cu m	Milligrams/cu m	0.001
	Grams/cu ft	28.317 x 10 ⁻⁹
	Grams/cu m	1.0 x 10 ⁻⁶
	Micrograms/cu ft	0.02832
	Pounds/1000 cu ft	62.43 x 10 ⁻⁹
Micrograms/cu ft	Milligrams/cu m	35.314 x 10 ⁻³
	Grams/cu ft	1.0 x 10 ⁻⁶
	Grams/cu m	35.314 x 10 ⁻⁶
	Micrograms/cu m	35.314
	Pounds/1000 cu ft	2.2046 x 10 ⁻⁶
Pounds/1000 cu ft	Milligrams/cu m	16.018×10^3
	Grams/cu ft	0.35314
	Micrograms/cu m	16.018 x 10 ⁶
	Grams/cu m	16.018
	Micrograms/cu ft	353.14 x 10 ³

AIRBORNE PARTICULATE MATTER

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

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To Convert From	То	Multiply By
Millimeters of mercury (0°C)	Inches of water (60°F)	0.5358
Inches of mercury (0°C)	Inches of water (60°F)	13.609
	Millimeters of mercury (0°C)	1.8663
Inches of water (60°F)	Inches of mercury (0°C)	73.48 x 10 ⁻³

SAMPLING PRESSURE

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

To Convert From	То	Multiply By
Milligrams/cu m	Micrograms/cu m	1000.0
	Micrograms/liter	1.0
	ppm by volume (20°C)	24.04/M
	ppm by weight	0.8347
	Pounds/cu ft	62.43 x 10 ⁻⁹
Micrograms/cu m	Milligrams/cu m	0.001
	Micrograms/liter	0.001
	ppm by volume (20°C)	0.02404/M
	ppm by weight	834.7 x 10 ⁻⁶
	Pounds/cu ft	62.43 x 10 ⁻¹²
Micrograms/liter	Milligrams/cu m	1.0
	Micrograms/cu m	1000.0
	ppm by volume (20°C)	24.04/M
	ppm by weight	0.8347
	Pounds/cu ft	62.43 x 10 ⁻⁹
ppm by volume (20°C)	Milligrams/cu m	M/24.04
	Micrograms/cu m	M/0.02404
	Micrograms/liter	M/24.04
	ppm by weight	M/28.8
	Pounds/cu ft	M/385.1 x 10 ⁶
ppm by weight	Milligrams/cu m	1.198
	Micrograms/cu m	1.198 x 10 ⁻³
	Micrograms/liter	1.198
	ppm by volume (20°C)	28.8/M
	Pounds/cu ft	7.48 x 10 ⁻⁶
Pounds/cu ft	Milligrams/cu m	16.018 x 10 ⁶
	Micrograms/cu m	16.018x 10 ⁹
	Micrograms/liter	16.018x 10 ⁶
	ppm by volume (20°C)	385.1 x 10 ⁶ /M
,	ppm by weight	133.7 x 10 ³

ATMOSPHERIC GASES

M = Molecular weight of gas.

CONVERSION FACTORS FOR COMMON AIR POLLUTION MEASUREMENTS (cont.).

To Convert From	То	Multiply By
Meters/sec	Kilometers/hr	3.6
	Feet/sec	3.281
	Miles/hr	2.237
Kilometers/hr	Meters/sec	0.2778
	Feet/sec	0.9113
	Miles/hr	0.6214
Feet/sec	Meters/sec	0.3048
	Kilometers/hr	1.09728
	Miles/hr	0.6818
Miles/hr	Meters/sec	0.4470
	Kilometers/hr	1.6093
	Feet/sec	1.4667

VELOCITY

ATMOSPHERIC PRESSURE

To Convert From	То	Multiply By
Atmospheres	Millimeters of mercury	760.0
	Inches of mercury	29.92
	Millibars	1013.2
Millimeters of mercury	Atmospheres	1.316 x 10 ⁻³
	Inches of mercury	39.37 x 10 ⁻³
	Millibars	1.333
Inches of mercury	Atmospheres	0.03333
	Millimeters of mercury	25.4005
	Millibars	33.35
Millibars	Atmospheres	0.00987
	Millimeters of mercury	0.75
	Inches of mercury	0.30

VOLUME EMISSIONS

To Convert From	То	Multiply By
Cubic m/min	Cubic ft/min	. 35.314
Cubic ft/min	Cubic m/min	0.0283

BOILER CONVERSION FACTORS

- : Megawatt = 10.5×10^6 BTU/hr (8 to 14 x 10⁶ BTU/hr)
- $\frac{1}{1000} \text{ Megawatt} = 8 \times 10^3 \text{ lb steam/hr}$ $(6 \text{ to ll } \times 10^3 \text{ lb steam/hr})$
- 1 BHP = 34.5 lb steam/hr
- 1 BHP = 45×10^3 BTU/hr (40 to 50 x 10³ BTU/hr)
- l lb steam/hr = 1.4×10^3 BTU/hr (1.2 to 1.7 x 10³ BTU/hr)

NOTES: In the relationships,

- Megawatt is the net electric power production of a steam electric power plant.
- BHP is boiler horsepower.
- Lb steam/hr is the steam production rate of the boiler.
- BTU/hr is the heat input rate to the boiler (based on the gross or high heating value of the fuel burned).

For less efficient (generally older and/or smaller) boiler operations, use the higher values expressed. For more efficient operations (generally newer and/or larger), use the lower vlaues.

VOLUME	cu. in.	m1.	liters	ounces (U. S. fl.)	gallons (U. S.)	barrels (U. S.)	cu. ft.
Cubic inches		16.3868	.0163868	0.5541	4.3290x10 ⁻³	1.37429x10 ⁻⁴	5.78704x10-4
Milliliters	0.061024		0.001	0.03381	2.6418x10-4	8.387x10-6	3.5316x10 ⁻⁵
Liters	61.024	1000	<u></u>	33.8147	0.26418	8-387x10-3	0.035316
Ounces (U. S. fl.)	1.80469	29.5729	0.029573		7.8125x10 ⁻³	2.48x10 ⁻⁴	1.0443x10 ⁻³
Gallons (U. S.)*	231	3785.3	3.7853	128		0.031746	0.13368
Barrels (U. S.)	7276.5	1.1924x10 ⁵	119.2369	4032.0	31.5		4.2109
Cubic feet	1728	2.8316x10 ⁴		957.568	7.481	0.23743	<u></u>

1U. S. gallon of water at 16.7°C (62°F) weighs 3.780 kg. or 8.337 pounds (avoir.)

MASS	grams	kilograms	ounces (avoir.)	pounds (avoir.)	grains	tons (U. S.)	milligrams_
Grams	••••	0.001	3.527×10-2	2.205x10-3	15.432	1.102x10-6	1000
Kilograms	1000	<u></u>	35.274	2.2046	15432	1.102x10-3	1x106
Ounces (avoir.)	28.350	0.028350	••••••	0.0625	437.5	3.125x10 ⁻⁵	2.8350x104
Pounds (avoir.)*	453.59	0.45359	16.0	<u></u>	7000	5.0x10-4	4.5359x10 ⁵
Grains	0.06480	6.480x10 ⁻⁵	2.286×10-3	1.429x10-4		7.142x10-8	64.799
Tons (U. S.)	9.072x10 ⁵	907.19	3.200x10 ⁴	2000	1.4x10 ⁷		9.0718x10 ⁸
Milligrams	0.001	1x10 ⁻⁶	3.527×10-5	2.205x10 ⁻⁶	0.015432	1.102x10 ⁻⁹	<u></u>

*Mass of 27.692 cubic inches water weighed in air at 4.0°C, 760 mm mercury pressure.

				·····				Υ		T T		·····
WORK AND ENERGY	g. cal.	kg. cal.	erga	Joules	BTU	ft. 1b.	kg. meters	L-Atu	HP Hours	ft. poundals	KWH	1711
Gram Calories		0.001	4.186x10 ⁷	4.186	3.9680x10-3	3.0874	0.42685	0.041311	1.5593x10-6	99.334	1.1628×10 ⁻⁶	1.1628×10-3
Kilogram Calorine	1000		4.186 1010	4186	3.9680	3087.4	426.85	41.311	1.5593x10-3	99334	1.1628×10-3	1.1628
Kilogiam calories.	2 2880-10-8	2 2000-10-11		1-10-7	9 4805-10-11	7 3756-10-8	1 0197-10-8	9 8689-10-10	3 7251-10-14	2.1730+10-6	2.7778-10-14	2.7728-10-11
Ergs	2.3009 810 -	2.3009210		1 110	7.4007410	7.3730410	1.017/ 410	7.0007.10	317231210	LISTSORIO	LITTORIO	2
Joules	0.23889	2.3889x10-4	1 x107		9.4805x10-4	0.73756	0.10197	9.8689x10-3	3.7251x10-7	23.730	2.7778x10-7	2.7778×10-4
BTU (mean)	251.98	0.25198	1.0548x1010	1054.8		777.98	107.56	10.409	3.9292×10-4	2.5030x10 ⁴	2.930×10 ⁻⁴	0.2930
Foot Pounds	0.32389	3.2389×10-4	1.35582×107	1.3558	1.2854×10-3		0.13825	0.013381	5.0505x10-7	32.174	3.7662×10-7	3.7662×10-4
Kilogram meters	2.3427	2.3427×10-3	9.8066x107	9.8066	9.2967 x10-3	7.2330		0.096781	3.6529×10 ⁻⁶	232.71	2.7241×10-6	2.7241×10-3
Liter Atmospheres	24.206	2.4206x10-2	1.0133x109	101.328	0.09606	74.735	10.333		3.7745×10-5	2404.5	2.8164x10-5	2.8164×10-2
Horsepower Hours	6.4130×105	641.30	2.6845×1013	2.6845x106	2454.0	1.9800x106	2.7374x10 ⁵	26494		6.3705x107	0.7457	745.7
	0.010067	10.067×10-6	4.21402×10 ⁵	0.04214	3.9952x10-5	0.031081	4.2972x10-3	4.1558x10-4	1.5697×10-8		1.17055x10-8	1.17055x10-5
Kilovett Hours	8.6001 x105	860.01	3.6000x1013	3.6000x106	3413.0	2.6552x106	3.6709x10-5	3.5529×106	1.3440	8.5430x107		1000
Watt Hours	860.01	0.86001	3.6000×1010	3600	3.4130	2655.3	367.09	3.5529x103	1.3410x10-3	8.5430x101	0.001	<u></u>
	[-									
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POWER	watts	kw	ft. 1b./sec	erg/sec	BTU/min	g. cm/sec	kg. cal/min	HP	Lumens	Joules/sec	BTU/hr.	
Watts		0.001	0.73756	1 x10 ⁷	0.056884	1.0197x10 ⁴	0.01433	1.341x10 ⁻³	668	1	3.41304	
Kilowatts	1000		737.56	1x10 ¹⁰	56.884	1.0197x10 ⁷	14.3334	1.3410	6.68x10 ⁵	1000	3413.04	
Foot pounds per second	1.35582	1.3558x10 ⁻³		1.3558x10 ⁷	0.077124	1.3826 x10 ⁴	0.019433	1.8182x10-3	906.28	1.3558	4.6274	
Ergs per second	1x10 ⁻⁷	1x10-10	7.3756x10-8		5.688x10 ⁻⁹	1.0197x10-3	1.4333x10 ⁻⁹	1.3410x10-10	6.6845x10-5	1 x10 ⁻⁷	3.4130x10 ⁻⁷	
BTU* per minute	17.580	0.017580	12.9600	1.7580x10 ⁸		1.7926x10 ⁵	0.2520	0.023575	11751	17.580	60	
Gram Centimeters	9.8067x10-5	9.8067x10 ⁻⁸	7.2330x10-5	980.665	5.5783x10-6		1.4056x10 ⁻⁶	1.3151×10 ⁻⁷	0.065552	9.8067x10 ⁻⁵	3.3470x10 ⁻⁴	
Kilogram colories	69.767	.069767	51.457	6.9770x108	3.9685	7.1146x10 ⁵		0.093557	46636	69.769	238.11	
Horsepower (U. S.)	745.7	0.7457	550	7.457x109	42.4176	7.6042x10 ⁶	10.688		498129	745.7	2545.1	
Lumens	1.496x10 ⁻³	1.496×10 ⁻⁶	1.0034x10-3	1.496x10 ⁴	8.5096x10 ⁻⁵	15.254	2.1437x10 ⁻⁵	2.0061x10 ⁻⁶		1.496x10-3	5.1069x10 ⁻³	
Joules per second	1	0,001	0.73756	1x10 ⁷	0.056884	1.0197×10 ⁴	0.01433	1.341x10 ⁻³	668		3.41304	
BTU [*] per hour	0.29299	2.9299×10 ⁻⁴	0.21610	2.9299x10 ⁶	0.01667	2.9878x103	4.1997x10-3	3.9291x10-4	195.80	0.29299		

*British Thermal Units (Mean)

Type Of Substance	Conversion Factors
Fuel	
Oil	1 bbl = 159 liters (42 gal)
Natural gas	1 therm = $100,000$ Btu (approx.25000 kcal)
Gaseous Pollutants	
0 ₃	1 ppm, volume = $1960\mu g/m^3$
NO ₂	1 ppm, volume = $1880\mu g/m^3$
SO ₂	1 ppm, volume = $2610\mu g/m^3$
H ₂ S	1 ppm, volume = 1390 μ g/m ³
со	1 ppm, volume = 1.14 mg/m^3
HC (as methane)	1 ppm, volume = 0.654 mg/m^3
Agricultural products	
Corn	1 bu = 25.4 kg = 56 lb
Milo	1 bu = 25.4 kg = 56 lb
Oats	1 bu = 14.5 kg = 32 lb
Barley	1 bu = 21.8 kg = 48 lb
Wheat	1 bu = 27.2 kg = 60 lb
Cotton	1 bale = 226 kg = 500 lb
Mineral products	
Brick	1 brick = 2.95 kg = 6.5 lb
Cement	1 bbl = 170 kg = 375 lb
Cement	$1 \text{ yd}^3 = 1130 \text{ kg} = 2500 \text{ lb}$
Concrete	$1 \text{ yd}^3 = 1820 \text{ kg} = 4000 \text{ lb}$
Mobile sources, fuel efficiency	
Motor vehicles	1.0 mi/gal = 0.426 km/liter
Waterborne vessels	1.0 gal/naut mi = 2.05 liters/km
Miscellaneous liquids	
Beer	1 bbl = 31.5 gal
Paint	1 gal = 4.5 to 6.82 kg = 10 to 15 lb
Varnish	1 gal = 3.18 kg = 7 lb
Whiskey	1 bbl = 190 liters = 50.2 gal
Water	1 gal = 3.81 kg = 8.3 lb

CONVERSION FACTORS FOR VARIOUS SUBSTANCES^a

^a Many of the conversion factors in this table represent average values and approximations and some of the values vary with temperature and pressure. These conversion factors should, however, be sufficiently accurate for general field use.

APPENDIX B.1

PARTICLE SIZE DISTRIBUTION DATA AND SIZED EMISSION FACTORS FOR SELECTED SOURCES

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EMISSION FACTORS

APPENDIX B.1

PARTICLE SIZE DISTRIBUTION DATA AND SIZED EMISSION FACTORS FOR SELECTED SOURCES

Introduction

This appendix presents particle size distributions and emission factors for miscellaneous sources or processes for which documented emission data were available. Generally, the sources of data used to develop particle size distributions and emission factors for this appendix were:

- 1. Source test reports in the files of the Emissions Monitoring, and Analysis Division of EPA's Office Of Air Quality Planning And Standards.
- 2. Source test reports in the Fine Particle Emission Information System (FPEIS), a computerized data base maintained by EPA's Air And Energy Engineering Research Laboratory, Office Of Research And Development.
- 3. A series of source tests titled Fine Particle Emissions From Stationary And Miscellaneous Sources In The South Coast Air Basin, by H. J. Taback.
- 4. Particle size distribution data reported in the literature by various individuals and companies.

Particle size data from FPEIS were mathematically normalized into more uniform and consistent data. Where EMB tests and Taback report data were filed in FPEIS, the normalized data were used in developing this appendix.

Information on each source category in Appendix B.1 is presented in a 2-page format: For a source category, a graph provided on the first page presents a particle size distribution expressed as the cumulative weight percent of particles less than a specified aerodynamic diameter (cut point), in micrometers. A sized emission factor can be derived from the mathematical product of a mass emission factor and the cumulative weight percent of particles smaller than a specific cut point in the graph. At the bottom of the page is a table of numerical values for particle size distributions and sized emission factors, in micrometers, at selected values of aerodynamic particle diameter. The second page gives some information on the data used to derive the particle size distributions.

Portions of the appendix denoted TBA in the table of contents refer to information that will be added at a later date.



Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg		
diameter, um	Wet scrubber controlled	Wet scrubber controlled		
2.5	46.3	0.37		
6.0	70.5	0.56		
10.0	97.1	0.78		

1.8 BAGASSE-FIRED BOILER: EXTERNAL COMBUSTION

NUMBER OF TESTS: 2, conducted after wet scrubber control

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	46.3	70.5	97.1
	Standard deviation (Cum. %):	0.9	0.9	1 .9
	Min (Cum. %):	45.4	69.6	95.2
	Max (Cum. %):	47.2	71.4	99.0

TOTAL PARTICULATE EMISSION FACTOR: Approximately 0.8 kg particulate/Mg bagasse charged to boiler. This factor is derived from AP-42, Section 1.8, 4/77, which states that the particulate emission factor from an uncontrolled bagasse-fired boiler is 8 kg/Mg and that wet scrubbers typically provide 90% particulate control.

SOURCE OPERATION: Source is a Riley Stoker Corp. vibrating grate spreader stoker boiler rated at 120,000 lb/hr but operated during this testing at 121% of rating. Average steam temperature and pressure were 579°F and 199 psig, respectively. Bagasse feed rate could not be measured, but was estimated to be about 41 (wet) tons/hr.

SAMPLING TECHNIQUE: Andersen Cascade Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Emission Test Report, U. S. Sugar Company, Bryant, FL, EMB-80-WFB-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1980.



Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
diameter, um	Uncontrolled	Uncontrolled
2.5	26.0	3.9
6.0	30.6	4.6
10.0	38.0	5.7

2.1 REFUSE INCINERATION: MUNICIPAL WASTE MASS BURN INCINERATOR

NUMBER OF TESTS: 7, conducted before control

STATISTICS:	Aerodynamic Particle Diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	26.0	30.6	38.0
	Standard deviation (Cum. %):	9.5	13.0	14.0
	Min (Cum. %):	18	22	24
	Max (Cum. %):	40	49	54

TOTAL PARTICULATE EMISSION FACTOR: 15 kg of particulate/Mg of refuse charged. Emission factor from AP-42 Section 2.1.

SOURCE OPERATION: Municipal incinerators reflected in the data base include various mass burning facilities of typical design and operation.

SAMPLING TECHNIQUE: Unknown

EMISSION FACTOR RATING: D

REFERENCE:

Determination of Uncontrolled Emissions, Product 2B, Montgomery County, Maryland, Roy F. Weston, Inc., West Chester, PA, August 1984.



Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
diameter, um	Uncontrolled	Uncontrolled
2.5	54.0	8.1
6.0	60.1	9.0
10.0	67.1	10.1
	Aerodynamic particle diameter, um 2.5 6.0 10.0	Aerodynamic particleCumulative wt. % < stated sizediameter, umUncontrolled2.554.06.060.110.067.1

2.1 REFUSE INCINERATION: MUNICIPAL WASTE MODULAR INCINERATOR

NUMBER OF TESTS: 3, conducted before control

STATISTICS:	Aerodynamic Particle Diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	54.0	60.1	67.1
	Standard deviation (Cum. %):	19.0	20.8	23.2
	Min (Cum. %):	34.5	35.9	37.5
	Max (Cum. %):	79.9	86.6	94.2

TOTAL PARTICULATE EMISSION FACTOR: 15 kg of particulate/Mg of refuse charged. Emission factor from AP-42 Section 2.1.

SOURCE OPERATION: Modular incinerator (2-chambered) operation was at 75.9% of the design process rate (10,000 lb/hr) and 101.2% of normal steam production rate. Natural gas is required to start the incinerator each week. Average waste charge rate was 1.983T/hr. Net heating value of garbage 4200-4800 Btu/lb garbage charged.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Emission Test Report, City of Salem, Salem, Va, EMB-80-WFB-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1980.



Aerodynamic	Cumulative wt. 2 < stated size	Emission factor, kg/Mg		
particle diameter, um	Water curtain controlled	Water curtain controlled		
2.5	28.6	1.39		
6.0	38.2	1.85		
10.0	46.7	2.26		
	Aerodynamic particle diameter, um 2.5 6.0 10.0	Aerodynamic particle diameter, umCumulative wt. 2 < stated size2.5Water curtain controlled2.528.66.038.210.046.7		

4.2.2.8 AUTOMOBILE AND LIGHT-DUTY TRUCK SURFACE COATING OPERATIONS: AUTOMOBILE SPRAY BOOTHS (WATER-BASE ENAMEL)

NUMBER OF TESTS: 2, conducted after water curtain control

STATISTICS:	FATISTICS: Aerodynamic particle diameter (μ m):			10.0
	Mean (Cum. %):	28.6	38.2	46.7
	Standard deviation (Cum. %):	14.0	16.8	20.6
	Min (Cum. %):	15.0	21.4	26.1
	Max (Cum. %):	42.2	54.9	67.2

TOTAL PARTICULATE EMISSION FACTOR: 4.84 kg particulate/Mg of water-base enamel sprayed. From References a and b.

SOURCE OPERATION: Source is a water-base enamel spray booth in an automotive assembly plant. Enamel spray rate is 568 lb/hour, but spray gun type is not identified. The spray booth exhaust rate is 95,000 scfm. Water flow rate to the water curtain control device is 7181 gal/min. Source is operating at 84% of design rate.

SAMPLING TECHNIQUE: SASS and Joy trains with cyclones

EMISSION FACTOR RATING: D

- a. H. J. Taback, Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin, PB 293 923/AS, National Technical Information Service, Springfield, VA, February 1979.
- b. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 234, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.



Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg		
diameter, um	Uncontrolled	Uncontrolled		
2.5	87.3	1.40		
6.0	95.0	1.52		
10.0	97.0	1.55		

6.1 CARBON BLACK: OIL FURNACE PROCESS OFFGAS BOILER

NUMBER OF TESTS: 3, conducted at offgas boiler outlet

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	87.3	95.0	97.0
	Standard Deviation (Cum. %):	2.3	3.7	8.0
	Min (Cum. %):	76.0	90.0	94.5
	Max (Cum. %):	94.0	99	100

TOTAL PARTICULATE EMISSION FACTOR: 1.6 kg particulate/Mg carbon black produced, from reference.

SOURCE OPERATION: Process operation: "normal" (production rate = 1900 kg/hr). Product is collected in fabric filter, but the offgas boiler outlet is uncontrolled.

SAMPLING TECHNIQUE: Brink Cascade Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Air Pollution Emission Test, Phillips Petroleum Company, Toledo, OH, EMB-73-CBK-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1974.



Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
	Uncontrolled	Uncontrolled
2.5	10.8	2.5
6.0	49.1	11.3
10.0	98.6	22.7

8.4 AMMONIUM SULFATE FERTILIZER: ROTARY DRYER

NUMBER OF TESTS: 3, conducted before control

STATISTICS:	Aerodynamic particle diameter (µm):	2.5	6.0	10.0
	Mean (Cum. %):	10.8	49.1	98.6
	Standard Deviation (Cum. %):	5.1	21.5	1.8
	Min (Cum. %):	4.5	20.3	96.0
	Max (Cum. %):	17.0	72.0	100.0

TOTAL PARTICULATE EMISSION FACTOR: 23 kg particulate/Mg of ammonium sulfate produced. Factor from AP-42, Section 8.4.

SOURCE OPERATION: Testing was conducted at 3 ammonium sulfate plants operating rotary dryers within the following production parameters:

Plant	Α	С	D
% of design process rate	100.6	40.1	100
production rate, Mg/hr	16.4	6.09	8.4

SAMPLING TECHNIQUE: Andersen Cascade Impactors

EMISSION FACTOR RATING: C

REFERENCE:

Ammonium Sulfate Manufacture — Background Information For Proposed Emission Standards, EPA-450/3-79-034a, U. S. Environmental Protection Agency, Research Triangle Park, NC, December 1979.



Particle diameter, um

Cumulative wt. % < stated size	Emission fa	ctor, kg/Mg	
	Uncon	Uncont roll ed	
Uncontrolled	(0.2)	(2.0)	
51.2	0.10	1.0	
100	0.20	2.0	
100	0.20	2.0	
	Cumulative wt. % < stated size Uncontrolled 51.2 100 100	Cumulative wt. % < stated size Emission fa Uncontrolled (0.2) 51.2 0.10 100 0.20 100 0.20	Cumulative wt. % < stated size Emission factor, kg/Mg Uncontrolled (0.2) (2.0) 51.2 0.10 1.0 100 0.20 2.0 100 0.20 2.0

EMISSION FACTORS

8.10 SULFURIC ACID: ABSORBER (ACID ONLY)

NUMBER OF TESTS: Not available

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	51.2	100	100
	Standard deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.2 to 2.0 kg acid mist/Mg sulfur charged, for uncontrolled 98% acid plants burning elemental sulfur. Emission factors are from AP-42 Section 8.10.

SOURCE OPERATION: Not available

SAMPLING TECHNIQUE: Brink Cascade Impactor

EMISSION FACTOR RATING: E

- a. Final Guideline Document: Control Of Sulfuric Acid Mist Emissions From Existing Sulfuric Acid Production Units, EPA-450/2-77-019, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1977.
- b. R. W. Kurek, Special Report On EPA Guidelines For State Emission Standards For Sulfuric Acid Plant Mist, E. I. du Pont de Nemours and Company, Wilmington, DE, June 1974.
- c. J. A. Brink, Jr., "Cascade Impactor For Adiabatic Measurements", Industrial and Engineering Chemistry, 50:647, April 1958.



Particle diameter, um

Aerodynamic	Cumulative wt. Z < stated size	Emission factor, kg/Mg
particle diameter, um	Uncontrolled	Uncontrolled
2.5	97.5	See Table 8.10-2
6.0	100	
10.0	100	
	1	

8.10 SULFURIC ACID: ABSORBER, 20% OLEUM

NUMBER OF TESTS: Not available

STATISTICS:	Aerodynamic particle diameter $(\mu m)^*$:	1.0	1.5	2.0
	Mean (Cum. %):	26	50	73
	Standard deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: Acid mist emissions from sulfuric acid plants are a function of type of feed as well as oleum content of product. See AP-42, Section 8.10, Tables 8.10-2 and 8.10-3.

SOURCE OPERATION: Not available

SAMPLING TECHNIQUE: Brink Cascade Impactor

EMISSION FACTOR RATING: E

- a. Final Guideline Document: Control Of Sulfuric Acid Mist Emissions From Existing Sulfuric Acid Production Units, EPA-450/2-77-019, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1977.
- b. R. W. Kurek, Special Report On EPA Guidelines For State Emission Standards For Sulfuric Acid Plant Mist, E. I. du Pont de Nemours and Company, Wilmington, DE, June 1974.
- c. J. A. Brink, Jr., "Cascade Impactor For Adiabatic Measurements", Industrial and Engineering Chemistry, 50:647, April 1958.

^{*100%} of the particulate is less than 2.5 μ m in diameter.



Particle diameter, um

Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
particle diameter, um	Uncontrolled	Uncontrolled
2.5	100	See Table 8.10-2
6.0	100	
10.0	100	

8.10 SULFURIC ACID: ABSORBER, 32% OLEUM

NUMBER OF TESTS: Not available

STATISTICS:	Aerodynamic particle diameter $(\mu m)^*$:	1.0	1.5	2.0
	Mean (Cum. %):	41	63	84
	Standard deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %);			

TOTAL PARTICULATE EMISSION FACTOR: Acid mist emissions from sulfuric acid plants are a function of type of feed as well as oleum content of product. See AP-42, Section 8.10, Table 8.10-2.

SOURCE OPERATION: Not available

SAMPLING TECHNIQUE: Brink Cascade Impactor

EMISSION FACTOR RATING: E

- a. Final Guideline Document: Control Of Sulfuric Acid Mist Emissions From Existing Sulfuric Acid Production Units, EPA-450/2-77-019, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1977.
- b. R. W. Kurek, Special Report On EPA Guidelines For State Emission Standards For Sulfuric Acid Plant Mist, E. I. du Pont de Nemours and Company, Wilmington, DE, June 1974.
- c. J. A. Brink, Jr., "Cascade Impactor For Adiabatic Measurements", Industrial and Engineering Chemistry, 50:647, April 1958.

^{*100%} of the particulate is less than 2.5 μ m in diameter.



8.10 SULFURIC ACID: SECONDARY ABSORBER

	Aerodynamic	Cumulative wt. Z < stated size	Emission factor, kg/Mg
	particle diameter, um	Uncontrolled	Uncontrolled
;	2.5	48	Not Available
,	6.0	78	Not Available
	10.0	87	Not Available

EMISSION FACTORS

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8.10 SULFURIC ACID: SECONDARY ABSORBER

NUMBER OF TESTS: Not available

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	1 0.0
	Mean (Cum. %):	48	78	87
	Standard Deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: Acid mist emission factors vary widely according to type of sulfur feedstock. See AP-42 Section 8.10 for guidance.

SOURCE OPERATION: Source is the second absorbing tower in a double absorption sulfuric acid plant. Acid mist loading is $175 - 350 \text{ mg/m}^3$.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: E

REFERENCE:

G. E. Harris and L. A. Rohlack, "Particulate Emissions From Non-fired Sources In Petroleum Refineries: A Review Of Existing Data", Publication No. 4363, American Petroleum Institute, Washington, DC, December 1982.

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Particle diameter, um

Aerodynamic	Cumulative wt.	. % < stated size	Emission factor, kg/Mg		
particle diameter, um	Uncontrolled	Fabric filter	Uncontroll ed	Fabric filter controlled	
2.5	0.3	3.3	0.01	0.004	
6.0	3.3	6.7	0.14	0.007	
10.0	6.9	10.6	0.29	0.011	

8.xx BORIC ACID DRYER

NUMBER OF	TESTS: (a) 1, conducted before controls (b) 1, conducted after fabric filter co	ontrol		
STATISTICS:	(a) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	0.3	3.3	6.9
	Standard Deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			
	(b) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	3.3	6.7	10.6
	Standard Deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: Before control, 4.15 kg particulate/Mg boric acid dried. After fabric filter control, 0.11 kg particulate/Mg boric acid dried. Emission factors from Reference a.

SOURCE OPERATION: 100% of design process rate.

SAMPLING TECHNIQUE: (a) Joy train with cyclones (b) SASS train with cyclones

EMISSION FACTOR RATING: E

- a. H. J. Taback, Fine Particle Emissions From Stationary And Miscellaneous Sources In The South Coast Air Basin, PB 293 923/AS, National Technical Information Service, Springfield, VA, February 1979.
- Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 236, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.



8.xx POTASH (POTASSIUM CHLORIDE) DRYER



Aerodynamic	Cumulative wt.	mulative wt. % < stated size Emission fact (kg/Mg)		
particle diameter (um)	um) Uncontrolled drop ventur scrubber		Uncontrolled	
2.5	0.95	5.0	0.31	
6.0	2.46	7.5	0.81	
10.0	4.07	9.0	1.34	
10.0	4.07	9.0	1.34	

8.xx POTASH (POTASSIUM CHLORIDE) DRYER

NUMBER OF T	ESTS: (a) 7, before control				
	(b) 1, after cyclone and high pre-	essure dro	op venturi	scrubber co	ntrol
STATISTICS: (a) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0	
	Mean (Cum. %):	0.95	2.46	4.07	
	Standard deviation (Cum. %):	0.68	2.37	4.34	
	Min (Cum. %):	0.22 [.]	0.65	1.20	
	Max (Cum. %):	2.20	7.50	13.50	
(b) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0	
	Mean (Cum. %):	5.0	7.5	9.0	
	Standard deviation (Cum. %):				
	Min (Cum. %):				
	Max (Cum. %):				

TOTAL PARTICULATE EMISSION FACTOR: Uncontrolled emissions of 33 kg particulate/Mg of potassium chloride product from dryer, from AP-42. It is assumed that particulate emissions from rotary gas-fired dryers for potassium chloride are similar to particulate emissions from rotary steam tube dryers for sodium carbonate.

SOURCE OPERATION: Potassium chloride is dried in a rotary gas-fired dryer.

SAMPLING TECHNIQUE: (a) Andersen Impactor (b) Andersen Impactor

EMISSION FACTOR RATING: C

- a. *Emission Test Report, Kerr-Magee, Trona, CA*, EMB-79-POT-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.
- b. *Emission Test Report, Kerr-Magee, Trona, CA*, EMB-79-POT-5, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.



8.xx POTASH (POTASSIUM SULFATE) DRYER

••••••	Aerodynamic	Cumulative wt. 7 < stated size	Emission factor, kg/Mg	; ;
	particle diameter (um)	Controlled with fabric filter	Controlled with fabric filter	
	2.5	18.0	0.006	
I	6.0	32.0	0.011	,
,	10.0	43.0	0.014	

EMISSION FACTORS

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8.xx POTASH (POTASSIUM SULFATE) DRYER

NUMBER OF TESTS: 2, conducted after fabric filter

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	18.0	32.0	43.0
	Standard deviation (Cum. %):	7.5	11.5	14.0
	Min (Cum. %):	10.5	21.0	29.0
	Max (Cum. %):	24.5	44.0	1 4.0

TOTAL PARTICULATE EMISSION FACTOR: After fabric filter control, 0.033 kg of particulate per Mg of potassium sulfate product from the dryer. Calculated from an uncontrolled emission factor of 33 kg/Mg and control efficiency of 99.9%. From Reference a and AP-42, Section 8.12. It is assumed that particulate emissions from rotary gas-fired dryers are similar to those from rotary steam tube dryers.

SOURCE OPERATION: Potassium sulfate is dried in a rotary gas-fired dryer.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: E

- a. Emission Test Report, Kerr-McGee, Trona, CA, EMB-79-POT-4, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.
- b. Emission Test Report, Kerr-McGee, Trona, CA, EMB-79-POT-5, Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1979.



Particle diameter, um

Aerodynamic	Cumulative wt.	% < stated size	Emission fact	tor (kg/bale)
particle	With	With cyclone &	With	With cyclone
diameter (um)	cyclone	wet scrubber	cyclone	& wet scrubber
2.5	8	11	0.007	0.001
6.0	33	26	0.028	0.003
10.0	62	52	0.053	0.006

9.7 COTTON GINNING: BATTERY CONDENSER

NUMBER OF	TES	STS: (a) 2, after cyclone (b) 3, after wet scrubber				
STATISTICS:	(a)	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0	
		Mean (Cum. %):	8	33	62	
		Standard deviation (Cum. %):				
		Min (Cum. %):				
		Max (Cum. %):		,		*
	(b)	Aerodynamic particle diameter (µm)				
		Mean (Cum. %.):	11	26	52	
		Standard deviation (Cum. %):				
		Min (Cum. %):				
		Max (Cum. %):				

TOTAL PARTICULATE EMISSION FACTOR: Particulate emission factor for battery condensers with typical controls is 0.09 kg (0.19 lb)/bale of cotton. Factor is from AP-42, Section 9.7. Factor with wet scrubber after cyclone is 0.012 kg (0.026 lb)/bale. Scrubber efficiency is 86%. From Reference b.

SOURCE OPERATION: During tests, source was operating at 100% of design capacity. No other information on source is available.

SAMPLING TECHNIQUE: UW Mark 3 Impactor

EMISSION FACTOR RATING: E

- a. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System (FPEIS), Series Report No. 27, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.
- b. Robert E. Lee, Jr., et al., "Concentration And Size Of Trace Metal Emissions From A Power Plant, A Steel Plant, And A Cotton Gin", Environmental Science And Technology, 9(7)643-7, July 1975.



Aerodynamic particle diameter (um)	Cumulative wt. After cyclone	X < stated size After cyclone & wet scrubber	Emission factor (kg/bale) After cyclone
2.5	I	11	0.004
6.0	20	74	0.07
10.0	54	92	0.20

EMISSION FACTORS

9.7 COTTON GINNING: LINT CLEANER AIR EXHAUST

NUMBER OF TESTS:	(a)	4, after cyclone	
	(b)	4, after cyclone and wet scrubber	

STATISTICS:	(a) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	1	20	54
	Standard deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			
	(b) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	11	74	92
	Standard deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.37 kg particulate/bale of cotton processed, with typical controls. Factor is from AP-42, Section 9.7.

SOURCE OPERATION: Testing was conducted while processing both machine-picked and groundharvested upland cotton, at a production rate of about 6.8 bales/hr.

SAMPLING TECHNIQUE: Coulter counter

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EMISSION FACTOR RATING: E

REFERENCE:

S. E. Hughs, *et al.*, "Collecting Particles From Gin Lint Cleaner Air Exhausts", presented at the 1981 Winter Meeting of the American Society Of Agricultural Engineers, Chicago, IL, December 1981.

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Aerodynamic particle Cumulative wgt. % <stated size Emission factor, kg/Mg diameter, um Uncontrolled Uncontrolled 2.5 13.8 0.13 30.5 0.33 6.0 10.0 49.0 0.56

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EMISSION FACTORS

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9.9.1 FEED AND GRAIN MILLS AND ELEVATORS: GRAIN UNLOADING IN COUNTRY ELEVATORS

NUMBER OF TESTS: 2, conducted before control

STATISTICS: Aerodynamic particle diameter (µm):		2.5	6.0	10.0
	Mean (Cum. %):	13.8	30.5	49.0
	Standard deviation (Cum. %):	3.3	2.5	_
	Min (Cum. %):	10.5	28.0	49.0
	Max (Cum. %):	17.0	33.0	49.0

TOTAL PARTICULATE EMISSION FACTOR: 0.3 kg particulate/Mg of grain unloaded, without control. Emission factor from AP-42, Section 9.9.1.

SOURCE OPERATION: During testing, the facility was continuously receiving wheat of low dockage. The elevator is equipped with a dust collection system that serves the dump pit boot and leg.

SAMPLING TECHNIQUE: Nelson Cascade Impactor

EMISSION FACTOR RATING: D

REFERENCES:

- a. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System (FPEIS), Series Report No. 154, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.
- b. Emission Test Report, Uniontown Co-op, Elevator No. 2, Uniontown, WA, Report No. 75-34, Washington State Department Of Ecology, Olympia, WA, October 1975.



Į	Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg	
	particle diameter, um	Uncontrolled	Uncontrolled	_
	2.5	16.8	0.08	•
	6.0	41.3	0.21	
	10.0	69.4	0.35	Į

9.9.1 FEED AND GRAIN MILLS AND ELEVATORS: CONVEYING

NUMBER OF TESTS: 2, conducted before control

STATISTICS: Aerodynamic particle diameter (μ m):		2.5	6.0	10.0
	Mean (Cum. %):	16.8	41.3	69.4
	Standard deviation (Cum. %):	6.9	16.3	27.3
	Min (Cum. %):	9.9	25.0	42.1
	Max (Cum. %):	23.7	57.7	96. 6

TOTAL PARTICULATE EMISSION FACTOR: 0.5 kg particulate/Mg of grain processed, without control. Emission factor from AP-42, Section 9.9.1.

SOURCE OPERATION: Grain is unloaded from barges by "marine leg" buckets lifting the grain from the barges and discharging it onto an enclosed belt conveyer, which transfers the grain to the elevator. These tests measured the combined emissions from the "marine leg" bucket unloader and the conveyer transfer points. Emission rates averaged 1956 lb particulate/hour (0.67 kg/Mg grain unloaded). Grains are corn and soy beans.

SAMPLING TECHNIQUE: Brink Model B Cascade Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Air Pollution Emission Test, Bunge Corporation, Destrehan, LA, EMB-74-GRN-7, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1974.



Aerodynamic		Cumulative wt. Z < Stated Size	Emission Factor (kg/Mg)
		Uncontrolled	Uncontrolled
	2.5	2.0	0.003
	6.0	8.0	0.01
	10.0	19.5	0.029
			1

9.9.1 FEED AND GRAIN MILLS AND ELEVATORS: RICE DRYER

NUMBER OF TESTS: 2, conducted on uncontrolled source.

STATISTICS:	Aerodynamic Particle Diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	2.0	8.0	19.5
	Standard Deviation (Cum. %):		3.3	9.4
	Min (Cum. %):	2.0	3.1	10.1
	Max (Cum. %):	2.0	9.7	28.9

TOTAL PARTICULATE EMISSION FACTOR: 0.15 kg particulate/Mg of rice dried. Factor from AP-42, Section 9.9.1. Table 9.9.1-1, footnote b for column dryer.

SOURCE OPERATION: Source operated at 100% of rated capacity, drying 90.8 Mg rice/hr. The dryer is heated by 4 9.5-kg/hr burners.

SAMPLING TECHNIQUE: SASS train with cyclones

EMISSION FACTOR RATING: D

REFERENCES:

- a. H. J. Taback, Fine Particle Emissions From Stationary And Miscellaneous Sources In The South Coast Air Basin, PB 293 923/AS, National Technical Information Service, Springfield, VA, February 1979.
- b. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 228, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.



	Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
	particle diameter, um	Uncontrolled	Uncontrolled
	2.5	27	0.20
	6.0	37	0.28
:	10.0	44	0.33
•			

9.9.2 FEED AND GRAIN MILLS AND ELEVATORS: CEREAL DRYER

NUMBER OF TESTS: 6, conducted before controls

STATISTICS: Aerodynamic particle diameter (µm):		2.5	6.0	10.0
	Mean (Cum. %):	27	37	44
	Standard deviation (Cum. %):	17	18	20
	Min (Cum. %):	13	20	22
	Max (Cum. %):	47	56	58

TOTAL PARTICULATE EMISSION FACTOR: 0.75 kg particulate/Mg cereal dried. Factor taken from AP-42, Section 9.9.2.

SOURCE OPERATION: Confidential

SAMPLING TECHNIQUE: Andersen Mark III Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Confidential test data from a major grain processor, PEI Associates, Inc., Golden, CO, January 1985.



Aerodynamic	Cum. wt. % < stated size	Emission factor, kg/Mg
diameter, um	Uncontrolled	Uncontrolled
2.5	70.6	3.5
6.0	82.7	4-1
10.0	90.0	4.5

9.9.4 ALFALFA DEHYDRATING: DRUM DRYER PRIMARY CYCLONE

NUMBER OF TESTS: 1, conducted before control

 STATISTICS: Aerodynamic particle diameter (μm):
 2.5
 6.0
 10.0

 Mean (Cum. %):
 70.6
 82.7
 90.0

 Standard deviation (Cum. %)
 Min (Cum. %):
 Max (Cum. %):

TOTAL PARTICULATE EMISSION FACTOR: 5.0 kg particulate/Mg alfalfa pellets before control. Factor from AP-42, Section 9.9.4.

SOURCE OPERATION: During this test, source dried 10 tons of alfalfa/hour in a direct-fired rotary dryer.

SAMPLING TECHNIQUE: Nelson Cascade Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 152, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

9.9.xx FEED AND GRAIN MILLS AND ELEVATORS: CAROB KIBBLE ROASTER



Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
diameter, um	Uncontrolled	Uncontrolled
2.5	3.0	0.11
6.0	3.2	0.12
10.0	9.6	0.36

9.9.xx FEED AND GRAIN MILLS AND ELEVATORS: CAROB KIBBLE ROASTER

NUMBER OF TESTS: 1, conducted before controls

 STATISTICS: Aerodynamic particle diameter (μm):
 2.5
 6.0
 10.0

 Mean (Cum. %):
 3.0
 3.2
 9.6

 Standard deviation (Cum. %):
 Min (Cum. %):
 Min (Cum. %):

 Max (Cum. %):
 Max (Cum. %):

TOTAL PARTICULATE EMISSION FACTOR: 3.8 kg/Mg carob kibble roasted. Factor from Reference a, p. 4-175.

SOURCE OPERATION: Source roasts 300 kg carob pods per hour, 100% of the design rate. Roaster heat input is 795 kJ/hr of natural gas.

SAMPLING TECHNIQUE: Joy train with 3 cyclones

EMISSION FACTOR RATING: E

REFERENCES:

- a. H. J. Taback, Fine Particle Emissions From Stationary And Miscellaneous Sources In The South Coast Air Basin, PB 293 923/AS, National Technical Information Service, Springfield, VA, February 1979.
- b. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System Series, Report No. 229, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

10.5 WOODWORKING WASTE COLLECTION OPERATIONS: BELT SANDER HOOD EXHAUST CYCLONE



Aerodynamic particle	Cumulative wt.	% < stated size	Emission factor, kg/hour of cyclone operation
diameter, um	Cyclone	After cyclone and fabric filter	After cyclone collector
2.5	2 9. 5	14.3	0.68
6.0	42.7	17.3	0.98
10.0	52.9	32.1	1.22

10.5 WOODWORKING WASTE COLLECTION OPERATIONS: BELT SANDER HOOD EXHAUST CYCLONE

10.0

52.9

10.0

32.1

NUMBER OF TH	ESTS: (a) 1, conducted after cyclone control (b) 1, after cyclone and fabric filter con	ntrol	
STATISTICS: (a) Aerodynamic particle diameter (µm):	2.5	6.0
	Mean (Cum. %):	29.5	42.7
	Standard deviation (Cum. %):		
	Min (Cum. %):		
	Max (Cum. %):		
(Ե) Aerodynamic particle diameter (µm):	2.5	6.0
	Mean (Cum. %.):	14.3	17.3
	Standard deviation (Cum. %):		
	Min (Cum. %):		

Max (Cum. %):

TOTAL PARTICULATE EMISSION FACTOR: 2.3 kg particulate/hr of cyclone operation. For cyclone-controlled source, this emission factor applies to typical large diameter cyclones into which wood waste is fed directly, not to cyclones that handle waste previously collected in cyclones. If baghouses are used for waste collection, particulate emissions will be negligible. Accordingly, no emission factor is provided for the fabric filter-controlled source. Factors from AP-42.

SOURCE OPERATION: Source was sanding 2-ply panels of mahogany veneer, at 100% of design process rate of 1110 m²/hr.

SAMPLING TECHNIQUE: (a) Joy train with 3 cyclones (b) SASS train with cyclones

EMISSION FACTOR RATING: E

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 238, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.

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-	Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
, 	particle diameter, um	After fabric filter control	After fabric filter control
1	2.5	16	0.002
	6.0	26	0.0025
	10.0	31	0.003

11.10 COAL CLEANING: DRY PROCESS

NUMBER OF TESTS: 1, conducted after fabric filter control

STATISTICS: Aerodynamic particle diameter (μ m): 2.5 6.0 10.0

Mean (Cum. %): 16 26 31 Standard deviation (Cum. %): Min (Cum. %): Max (Cum. %):

TOTAL PARTICULATE EMISSION FACTOR: 0.01 kg particulate/Mg of coal processed. Emission factor is calculated from data in AP-42, Section 11.10, assuming 99% particulate control by fabric filter.

SOURCE OPERATION: Source cleans coal with the dry (air table) process. Average coal feed rate during testing was 70 tons/hr/table.

SAMPLING TECHNIQUE: Coulter counter

EMISSION FACTOR RATING: E

REFERENCE:

R. W. Kling, Emissions From The Florence Mining Company Coal Processing Plant At Seward, PA, Report No. 72-CI-4, York Research Corporation, Stamford, CT, February 1972.



11.10 COAL CLEANING: THERMAL DRYER

Particle diameter, um

Aerodynamic	Cumulative wt	Cumulative wt. % < stated size		actor, kg/Mg	
particle diameter. um	After Uncontrolled wet scrubber		Uncontrolled	After Wet scrubber	
2.5	42	53	1.47	0.016	
6.0	86	85	3.01	0.026	
10.0	96	91	3.36	0.027	

11.10 COAL CLEANING: THERMAL DRYER

NUMBER OF TE	STS: (a) 1, conducted before control(b) 1, conducted after wet scrubber	control		
STATISTICS: (a)	Aerodynamic particle diameter (µm):	2.5	6.0	10.0
	Mean (Cum. %):	42	86	96
	Standard deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			
(b)) Aerodynamic particle diamter (μm):	2.5	6.0	10.0
	Mean (Cum. %):	53	85	91
	Standard deviation (Cum. %):			
	Min (Cum. %):	,-		
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 3.5 kg particulate/Mg of coal processed (after cyclone) before wet scrubber control. After wet scrubber control, 0.03 kg/Mg. These are sitespecific emission factors and are calculated from process data measured during source testing.

SOURCE OPERATION: Source operates a thermal dryer to dry coal cleaned by wet cleaning process. Combustion zone in the thermal dryer is about 1000°F, and the air temperature at the dryer exit is about 125°F. Coal processing rate is about 450 tons per hour. Product is collected in cyclones.

SAMPLING TECHNIQUE: (a) Coulter counter

(b) Each sample was dispersed with aerosol OT, and further dispersed using an ultrasonic bath. Isoton was the electrolyte used.

EMISSION FACTOR RATING: E

REFERENCE:

R. W. Kling, Emission Test Report, Island Creek Coal Company Coal Processing Plant, Vansant, Virgina, Report No. Y-7730-H, York Research Corporation, Stamford, CT, February 1972.

.



Aerodynamic	Cumulative wt.	% < stated size	Emission factor, kg/Mg	,
particle		Cyclone		
diameter, um	Uncontrolled	controlled	Uncont roll ed	1
:				1
2.5	9.6	21.3	0.07	1
				;
6.0	17.5	31.8	0.12	
				1
10.0	26.5	43.7	0.19	

11.10 COAL PROCESSING: THERMAL INCINERATOR

NUMBER OF	TEST	 S: (a) 2, conducted before controls (b) 2, conducted after multicyclone control 	ntrol		
STATISTICS:	(a)	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
		Mean (Cum. %):	9.6	17.5	26.5
		Standard deviation (Cum. %):			
		Min (Cum. %):			
		Max (Cum. %):			
	(b)	Aerodynamic particle diamter (μ m):	2.5	6.0	10.0
		Mean (Cum. %):	26.4	35.8	46.6
		Standard deviation (Cum. %):			
		Min (Cum. %):			
		Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.7 kg particulate/Mg coal dried, before multicyclone control. Factor from AP-42, Section 11.10.

SOURCE OPERATION; Source is a thermal incinerator controlling gaseous emissions from a rotary kiln drying coal. No additional operating data are available.

SAMPLING TECHNIQUE: Andersen Mark III Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Confidential test data from a major coal processor, PEI Associates, Inc., Golden, CO, January 1985.



Aerodynamic	mic <u>Cumulative wt. % < stated size</u>		Emission factor (kg/Mg)
particle diameter (um)	Wet scrubber and settling chamber	Wet scrubber	Wet scrubber and settling chamber
2.5	55	55	0.97
6.0	65	75	1.15
10.0	81	84	1.43

11.20 LIGHTWEIGHT AGGREGATE (CLAY): COAL-FIRED ROTARY KILN

NUMBER OF TESTS: (a) 4, conducted after wet scrubber control (b) 8, conducted after settling chamber and wet scrubber control

STATISTICS: (a) Aerodynamic particle diameter, (μm) : 2.5 6.0 10.0 55 84 Mean (Cum. %): 75 Standard Deviation (Cum. %): Min (Cum. %): Max (Cum. %): (b) Aerodynamic particle diameter, (μm) : 2.5 6.0 10.0 Mean (Cum. %): 55 65 81

Standard deviation (Cum. %): Min (Cum. %): Max (Cum. %):

TOTAL PARTICULATE EMISSION FACTOR: 1.77 kg particulate/Mg of clay processed, after control by settling chamber and wet scrubber. Calculated from data in Reference c.

SOURCE OPERATION: Sources produce lightweight clay aggregate in pulverized coal-fired rotary kilns. Kiln capacity for Source b is 750 tons/day, and operation is continuous.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: C

REFERENCES:

- a. Emission Test Report, Lightweight Aggregate Industry, Texas Industries, Inc., EMB-80-LWA-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1981.
- b. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 341, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.
- c. Emission Test Report, Lightweight Aggregate Industry, Arkansas Lightweight Aggregate Corporation, EMB-80-LWA-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1981.



Particle diameter, um

Aerodynamic	Cumulative wt. 2 < stated size	Emission factor, kg/Mg		
particle diameter, um	Uncontrolled	Uncontrolled		
2.5	37.2	13.0		
6.0	74.8	26.2		
10.0	89.5	31.3		

11.20 LIGHTWEIGHT AGGREGATE (CLAY): DRYER

NUMBER OF TESTS: 5, conducted before controls

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	37.2	74.8	89.5
	Standard deviation (Cum. %):	3.4	5.6	3.6
	Min (Cum. %):	32.3	68.9	85.5
	Max (Cum. %):	41.0	80.8	92.7

TOTAL PARTICULATE EMISSION FACTOR: 65 kg/Mg clay feed to dryer. From AP-42, Section 11.20.

SOURCE OPERATION: No information on source operation is available

SAMPLING TECHNIQUE: Brink Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 88, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.



Aerodynamic	Cumulative wt.	% < stated size	Emission factor, kg/Mg
particle diameter, um	Multiclone	Fabric filter	Multiclone
2.5	19.3	39	0.03
6.0	38.1	48	0.06
10.0	56.7	54	0.09

11.20 LIGHTWEIGHT AGGREGATE (CLAY): RECIPROCATING GRATE CLINKER COOLER

NUMBER OF TESTS: (a) 12, conducted after Multicyclone control

(b) 4, conducted after Multicyclone and fabric filter control

STATISTICS:	(a) Aerodynamic particle diameter (µm):	2.5	6.0	10.0
	Mean (Cum. %):	1 9.3	38.1	56.7
	Standard deviation (Cum. %):	7.9	14.9	17.9
	Min (Cum. %):	9.3	18.6	29.2
	Max (Cum. %):	34.6	61.4	76.6
	(b) Aerodynamic particle diameter (µm):	2.5	6.0	10.0
	Mean (Cum. %):	39	48	54
	Standard deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.157 kg particulate/Mg clay processed, after multicyclone control. Factor calculated from data in Reference b. After fabric filter control, particulate emissions are negligible.

SOURCE OPERATION: Sources produce lightweight clay aggregate in a coal-fired rotary kiln and reciprocating grate clinker cooler.

SAMPLING TECHNIQUE: (a) Andersen Impactor (b) Andersen Impactor

EMISSION FACTOR RATING: C

REFERENCES:

- a. Emission Test Report, Lightweight Aggregate Industry, Texas Industries, Inc., EMB-80-LWA-3, in U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1981.
- b. Emission Test Report, Lightweight Aggregate Industry, Arkansas Lightweight Aggregate Corporation, EMB-80-LWA-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1981.
- c. Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 342, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.



Aerodynamic	Cumulative wt. Z < stated size	Emission factor, kg/Mg
particle diameter, um	Settling chamber control	Settling chamber control
2.5	8.2	0.007
6.0	17.6	0.014
10.0	25.6	0.020

11.20 LIGHTWEIGHT AGGREGATE (SHALE): RECIPROCATING GRATE CLINKER COOLER

11.20 LIGHTWEIGHT AGGREGATE (SHALE): RECIPROCATING GRATE CLINKER COOLER

NUMBER OF TESTS: 4, conducted after settling chamber control

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	8.2	17.6	25.6
	Standard deviation (Cum. %):	4.3	2.8	1.7
	Min (Cum. %):	4.0	15.0	24.0
	Max (Cum. %):	14.0	21.0	28.0

TOTAL PARTICULATE EMISSION FACTOR: 0.08 kg particulate/Mg of aggregate produced. Factor calculated from data in reference.

SOURCE OPERATION: Source operates 2 kilns to produce lightweight shale aggregate, which is cooled and classified on a reciprocating grate clinker cooler. Normal production rate of the tested kiln is 23 tons/hr, about 66% of rated capacity. Kiln rotates at 2.8 rpm. Feed end temperature is 1100°F.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: B

REFERENCE:

Emission Test Report, Lightweight Aggregate Industry, Vulcan Materials Company, EMB-80-LWA-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1982.



Aerodynamic	Cumulative wt. % < stated size		Emission factor, kg/Mg	
particle	Without	After wet	Without	After wet
diameter, um	controls	scrubber control	controls	scrubber control
2.5	13	33	7.3	0.59
6.0	29	36	16.2	0.65
10.0	42	39	23.5	0.70

11.20 LIGHTWEIGHT AGGREGATE (SLATE): COAL-FIRED ROTARY KILN

NUMBER OF TESTS: (a) 3, conducted before control (b) 5, conducted after wet scrubber (control		
STATISTICS: (a) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
Mean (Cum. %):	13.0	29.0	42.0
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			
(b) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
Mean (Cum. %):	33.0	36.0	39.0
Standard deviation (Cum. %):			
Min (Cum. %):			
Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: For uncontrolled source, 56.0 kg particulate/Mg of feed. After wet scrubber control, 1.8 kg particulate/Mg of feed. Factors are calculated from data in reference.

SOURCE OPERATION: Source produces lightweight aggregate from slate in coal-fired rotary kiln and reciprocating grate clinker cooler. During testing source was operating at a feed rate of 33 tons/hr, 83% rated capacity. Firing zone temperatures are about 2125°F and kiln rotates at 3.25 rpm.

SAMPLING TECHNIQUE: (a) Bacho (b) Andersen Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Emission Test Report, Lightweight Aggregate Industry, Galite Corporation, EMB-80-LWA-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1982.



11.20 LIGHTWEIGHT AGGREGATE (SLATE): RECIPROCATING GRATE CLINKER COOLER

Particle diameter, um

Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg		
particle diameter, um	After settling chamber control	After settling chamber control		
2.5	9.8	0.02		
6.0	23.6	0.05		
10.0	41.0	0.09		

11.20 LIGHTWEIGHT AGGREGATE (SLATE): RECIPROCATING GRATE CLINKER COOLER

NUMBER OF TESTS: 5, conducted after settling chamber control

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	9.8	23.6	41.0
	Standard deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 0.22 kg particulate/Mg of raw material feed. Factor calculated from data in reference.

SOURCE OPERATION: Source produces lightweight slate aggregate in a coal-fired kiln and a reciprocating grate clinker cooler. During testing, source was operating at a feed rate of 33 tons/hr, 83% of rated capacity. Firing zone temperatures are about 2125°F, and kiln rotates at 3.25 rpm.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Emission Test Report, Lightweight Aggregate Industry, Galite Corporation, EMB-80-LWA-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, February 1982.



Particle diameter, um

Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
particle	After cyclone ^a and	After cyclone ^a and
diameter, um	wet scrubber	wet scrubber
2.5	94.0	0.064
	07.0	0.077
6.0	97.0	0.000
10.0	98.0	0.067
10.0	20.0	0.007

^aCyclones are typically used in phosphate rock processing as product collectors. Uncontrolled emissions are emissions in the air exhausted from such cyclones.

11.21 PHOSPHATE ROCK PROCESSING: CALCINER

NUMBER OF TESTS: 6, conducted after wet scrubber control

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	94.0	97.0	98.0
	Standard deviation (Cum. %):	2.5	1.6	1.5
	Min (Cum. %):	89.0	95.0	96.0
	Max (Cum. %):	98.0	99.2	99.7

TOTAL PARTICULATE EMISSION FACTOR: 0.0685 kg particulate/Mg of phosphate rock calcined, after collection of airborne product in a cyclone, and wet scrubber controls. Factor from reference cited below.

SOURCE OPERATION: Source is a phosphate rock calciner fired with No. 2 oil, with a rated capacity of 70 tons/hr. Feed to the calciner is beneficiated rock.

SAMPLING TECHNIQUE: Andersen Impactor.

EMISSION FACTOR RATING: C

REFERENCE:

Air Pollution Emission Test, Beker Industries, Inc., Conda, ID, EMB-75-PRP-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1975.



11.21 PHOSPHATE ROCK PROCESSING: OIL-FIRED ROTARY AND FLUIDIZED-BED TANDEM DRYERS

Cumulative wt. % < stated size Emission factor, kg/h		
After wet scrubber and	After wet scrubber and	
ESP control	ESP control	
78.0	0.010	
88.8	0.011	
93.8	0.012	
	Cumulative wt. % < stated size After wet scrubber and ESP control 78.0 88.8 93.8	

11.21 PHOSPHATE ROCK PROCESSING: OIL-FIRED ROTARY AND FLUIDIZED-BED TANDEM DRYERS

NUMBER OF TESTS: 2, conducted after wet scrubber and electrostatic precipitator control

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	78.0	88.8	93.8
	Standard deviation (Cum. %):	22.6	9.6	2.5
	Min (Cum. %):	62	82	92
	Max (Cum. %):	94	95	95

TOTAL PARTICULATE EMISSION FACTOR: 0.0125 kg particulate/Mg phosphate rock processed, after collection of airborne product in a cyclone and wet scrubber/ESP controls. Factor from reference cited below.

SOURCE OPERATION: Source operates a rotary and a fluidized bed dryer to dry various types of phosphate rock. Both dryers are fired with No. 5 fuel oil, and exhaust into a common duct. The rated capacity of the rotary dryer is 300 tons/hr, and that of the fluidized bed dryer is 150-200 tons/hr. During testing, source was operating at 67.7% of rated capacity.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Air Pollution Emission Test, W. R. Grace Chemical Company, Bartow, FL, EMB-75-PRP-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1976.


Aerodynamic	Cumulative	wt. % < stated size	Emission	factor, kg/Mg
particle diameter, (um)	After cyclone ^a	After wet scrubber	After cyclone ^a	After wet scrubber
2.5	15.7	89	0.38	0.017
6.0	41.3	92.3	1.00	0.018
10.0	58.3	96.6	1.41	0.018

^aCyclones are typically used in phosphate rock processing as product collectors. Uncontrolled emissions are emissions in the air exhausted from such cyclones.

11.21 PHOSPHATE ROCK PROCESSING: OIL-FIRED ROTARY DRYER

NUMBER	OF	TESTS:	(a)	3,	conducted	after	cyclone	
				-		-		

(b) 2, conducted after wet scrubber control

STATISTICS:	(a)	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
		Mean (Cum. %):	15.7	41.3	58.3
		Standard deviation (Cum. %):	5.5	9.6	13.9
		Min (Cum. %):	12	30	43
		Max (Cum. %):	22	48	70
	(b)	Aerodynamic particle diameter (µm):	2.5	6.0	10.0
		Mean (Cum. %):	89.0	92.3	96.6
		Standard Deviation (Cum. %):	7.1	6.0	3.7
		Min (Cum. %):	84	88	94
		Max (Cum. %):	94	96	9 9

Impactor cut points for the tests conducted before control are small, and many of the data points are extrapolated. These particle size distributions are related to specific equipment and source operation, and are most applicable to particulate emissions from similar sources operating similar equipment. Table 11.21-2, Section 11.21, AP-42 presents particle size distributions for generic phosphate rock dryers.

TOTAL PARTICULATE EMISSION FACTORS: After cyclone, 2.419 kg particulate/Mg rock processed. After wet scrubber control, 0.019 kg/Mg. Factors from reference cited below.

SOURCE OPERATION: Source dries phosphate rock in #6 oil-fired rotary dryer. During these tests, source operated at 69% of rated dryer capacity of 350 tons/day, and processed coarse pebble rock.

SAMPLING TECHNIQUE: (a) Brinks Cascade Impactor (b) Andersen Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Air Pollution Emission Test, Mobil Chemical, Nichols, FL, EMB-75-PRP-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1976.



Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
diameter, um	After cyclone ^a	After cyclone ^a
2.5	6.5	0.05
6.0	19.0	0.14
10.0	30.8	0.22

^aCyclones are typically used in phosphate rock processing as product collectors. Uncontrolled emissions are emissions in the air exhausted from such cyclones.

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11.21 PHOSPHATE ROCK PROCESSING: BALL MILL

NUMBER OF TESTS: 4, conducted after cyclone

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	6.5	19.0	30.8
	Standard deviation (Cum. %):	3.5	0.9	2.6
	Min (Cum. %):	3	18	28
	Max (Cum. %):	11	20	33

Impactor cutpoints were small, and most data points were extrapolated.

TOTAL PARTICULATE EMISSION FACTOR: 0.73 kg particulate/Mg of phosphate rock milled, after collection of airborne product in cyclone. Factor from reference cited below.

SOURCE OPERATION: Source mills western phosphate rock. During testing source was operating at 101% of rated capacity, producing 80 tons/hr.

SAMPLING TECHNIQUE: Brink Impactor

EMISSION FACTOR RATING: C

REFERENCE:

Air Pollution Emission Test, Beker Industries, Inc., Conda, ID, EMB-75-PRP-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1975.



Aerodynamic	Cumulative wt. 7 < stated size		Emissic	on factor, kg/Mg
particle diameter um	After cyclone ^a	After fabric filter	After cyclone ^a	After fabric filter
diameter, un			0/02000	
2.5	21	25	0.27	Negligible
6.0	45	70	0.58	Negligible
10.0	62	90	0.79	Negligible

² Cyclones are typically used in phosphate rock processing as product collectors. Uncontrolled emissions are emissions in the air exhausted from such cyclones.

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11.21 PHOSPHATE ROCK PROCESSING: ROLLER MILL AND BOWL MILL GRINDING

NUMBER OF TESTS: (a) 2, conducted after cyclone (b) 1, conducted after fabric filter control

STATISTICS:	(a)	Aerodynamic particle diameter (µm):	2.5	6.0	10.0
		Mean (Cum. %):	21.0	45.0	62.0
		Standard deviation (Cum. %):	1.0	1.0	0
		Min (Cum. %):	20.0	44.0	62.0
		Max (Cum. %):	22.0	46.0	62.0
	(b)	Aerodynamic particle diamter (μ m):	2.5	6.0	10.0
		Mean (Cum. %):	25	70	9 0
		Standard deviation (Cum. %):			
		Min (Cum. %):			
		Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR. 0.73 kg particulate/Mg of rock processed, after collection of airborne product in a cyclone. After fabric filter control, 0.001 kg particulate/Mg rock processed. Factors calculated from data in reference cited below. See Table 11.21-3 for guidance.

SOURCE OPERATION: During testing, source was operating at 100% of design process rate. Source operates 1 roller mill with a rated capacity of 25 tons/hr of feed, and 1 bowl mill with a rated capacity of 50 tons/hr of feed. After product has been collected in cyclones, emissions from each mill are vented to a coin baghouse. Source operates 6 days/week, and processes Florida rock.

SAMPLING TECHNIQUE: (a) Brink Cascade Impactor (b) Andersen Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Air Pollution Emission Test, The Royster Company, Mulberry, FL, EMB-75-PRP-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1976.



Aerodynamic	Cumulative wt. Z < stated size	Emission factor, kg/Mg	-
diameter, um	Before controls	Before controls	1
2.5	30 • 1	5.9	:
6.0	42.4	8.3	ł
10.0	56 • 4	11.1	•
			,

11.26 NONMETALLIC MINERALS: TALC PEBBLE MILL

NUMBER OF TESTS: 2, conducted before controls

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	30.1	42.4	56.4
	Standard deviation (Cum. %):	0.8	0.2	0.4
	Min (Cum. %):	29.5	42.2	56.1
	Max (Cum. %):	30.6	42.5	56.6

TOTAL PARTICULATE EMISSION FACTOR: 19.6 kg particulate/Mg ore processed. Calculated from data in reference.

SOURCE OPERATION: Source crushes talc ore then grinds crushed ore in a pebble mill. During testing, source operation was normal according to the operators. An addendum to the reference indicates throughput varied between 2.8 and 4.4 tons/hr during these tests.

SAMPLING TECHNIQUE: Sample was collected in an alundum thimble and analyzed with a Spectrex Prototron Particle Counter Model ILI 1000.

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, Pfizer, Inc., Victorville, CA, EMB-77-NMM-5, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1977.



Cumulative wt. % < stated size	Emission factor, kg/Mg
Before controls	Before controls
11.5	1.5
22.8	2.9
32.3	4.2
	Cumulative wt. % < stated size Before controls 11.5 22.8 32.3

11.xx NONMETALLIC MINERALS: FELDSPAR BALL MILL

NUMBER OF TESTS: 2, conducted before controls

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	11.5	22.8	32.3
	Standard deviation (Cum. %):	6.4	7.4	6.7
	Min (Cum. %):	7.0	17.5	27.5
	Max (Cum. %):	16.0	28.0	37.0

TOTAL PARTICULATE EMISSION FACTOR: 12.9 kg particulate/Mg feldspar produced. Calculated from data in reference and related documents.

SOURCE OPERATION: After crushing and grinding of feldspar ore, source produces feldspar powder in a ball mill.

SAMPLING TECHNIQUE: Alundum thimble followed by 12-inch section of stainless steel probe followed by 47-mm type SGA filter contained in a stainless steel Gelman filter holder. Laboratory analysis methods: microsieve and electronic particle counter.

EMISSION FACTOR RATING: D

REFERENCE:

Air Pollution Emission Test, International Minerals and Chemical Company, Spruce Pine, NC, EMB-76-NMM-1, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1976.



Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
particle diameter, um	After fabric filter control	After fabric filter control
2.5	10	0.04
6.0	30	0.11
10.0	48	0.18

EMISSION FACTORS

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11.xx NONMETALLIC MINERALS: FLUORSPAR ORE ROTARY DRUM DRYER

NUMBER OF TESTS: 1, conducted after fabric filter control

STATISTICS: Aerodynamic particle diameter (µm): 2.5 6.0 10.0

Mean (Cum. %): 10 30 48 Standard deviation (Cum. %): Min (Cum. %): Max (Cum. %):

TOTAL PARTICULATE EMISSION FACTOR: 0.375 kg particulate/Mg ore dried, after fabric filter control. Factors from reference.

SOURCE OPERATION: Source dries fluorspar ore in a rotary drum dryer at a feed rate of 2 tons/hr.

SAMPLING TECHNIQUE: Andersen Mark III Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Confidential test data from a major fluorspar ore processor, PEI Associates, Inc., Golden, CO, January 1985.

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Particle diameter, um

Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg
particle diameter, um	Fabric filter controlled	Fabric filter controlled
2.5	50.0	0.00025
6.0	62.0	0.0003
10.0	68.0	0.0003

12.1 PRIMARY ALUMINUM PRODUCTION: BAUXITE PROCESSING - FINE ORE STORAGE

NUMBER OF TESTS: 2, after fabric filter control

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	50.0	62.0	6 8.0
	Standard deviation (Cum. %):	15.0	19.0	20.0
	Min (Cum. %):	35.0	43.0	48.0
	Max (Cum. %):	65.0	81.0	88.0

TOTAL PARTICULATE EMISSION FACTOR: 0.0005 kg particulate/Mg of ore filled, with fabric filter control. Factor calculated from emission and process data in reference.

SOURCE OPERATION: The facility purifies bauxite to alumina. Bauxite ore, unloaded from ships, is conveyed to storage bins from which it is fed to the alumina refining process. These tests measured the emissions from the bauxite ore storage bin filling operation (the ore drop from the conveyer into the bin), after fabric filter control. Normal bin filling rate is between 425 and 475 tons per hour.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Emission Test Report, Reynolds Metals Company, Corpus Christi, TX, EMB-80-MET-9, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1980.



12.1 PRIMARY ALUMINUM PRODUCTION: BAUXITE PROCESSING -UNLOADING ORE FROM SHIP

Aerodynamic particle diameter, um	Cumulative wt. % < stated size Wet scrubber controlled	Emission factor, kg/Mg Wet scrubber controlled
2.5	60.5	0.0024
6.0	67.0	0.0027
10.0	70.0	0.0028

12.1 PRIMARY ALUMINUM PRODUCTION: BAUXITE PROCESSING -UNLOADING ORE FROM SHIP

NUMBER OF TESTS: 1, after venturi scrubber control

 STATISTICS: Aerodynamic particle diameter (μm):
 2.5
 6.0
 10.0

 Mean (Cum. %):
 60.5
 67.0
 70.0

 Standard deviation (Cum. %):
 Min (Cum. %):
 Max (Cum. %):

TOTAL PARTICULATE EMISSION FACTOR: 0.004 kg particulate/Mg bauxite ore unloaded after scrubber control. Factor calculated from emission and process data contained in reference.

SOURCE OPERATION: The facility purifies bauxite to alumina. Ship unloading facility normally operates at 1500-1700 tons/hr, using a self-contained extendable boom conveyor that interfaces with a dockside conveyor belt through an accordion chute. The emissions originate at the point of transfer of the bauxite ore from the ship's boom conveyer as the ore drops through the chute onto the dockside conveyer. Emissions are ducted to a dry cyclone and then to a Venturi scrubber. Design pressure drop across scrubber is 15 inches, and efficiency during test was 98.4%.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Emission Test Report, Reynolds Metals Company, Corpus Christi, TX, EMB-80-MET-9, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1980.



Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg	c
diameter, um	Uncontrolled	Uncontrolled	;
2.5	72.2	11.6	ł
6.0	76.3	12.2	
10.0	82.0	13.1	•

12.13 STEEL FOUNDRIES: CASTINGS SHAKEOUT

NUMBER OF TESTS: 2, conducted at castings shakeout exhaust hood before controls

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	72.2	76.3	82.0
	Standard deviation (Cum. %):	5.4	6.9	4.3
	Min (Cum. %):	66.7	69.5	77.7
	Max (Cum. %):	77.6	83.1	86.3

TOTAL PARTICULATE EMISSION FACTOR: 16 kg particulate/Mg metal melted, without controls. Although no nonfurnace emission factors are available for steel foundries, emissions are presumed to be similar to those in iron foundries. Nonfurnace emission factors for iron foundries are presented in AP-42, Section 12.13.

SOURCE OPERATION: Source is a steel foundry casting steel pipe. Pipe molds are broken up at the castings shakeout operation. No additional information is available.

SAMPLING TECHNIQUE: Brink Model BMS-11 Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 117, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.



-	Aerodynamic	Cumulative wt. %	<pre>< stated size</pre>	Emission Fact	or (kg/Mg)
, , ,	particle diameter, um	Uncontrolled	ESP	Uncontrolled	ESP
	2.5	79.6	49.3	4.4	0.14
i	6.0	82.8	58.6	4.5	0.16
	10.0	85.4	66.8	4.7	0.18

12.13 STEEL FOUNDRIES: OPEN HEARTH EXHAUST

NUMBER OF 7	TESTS: (a) 1, conducted before control (b) 1, conducted after ESP control			
STATISTICS:	(a) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	79.6	82.8	85.4
	Standard Deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			
	(b) Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	49.3	58.6	66.8
	Standard Deviation (Cum. %):			
	Min (Cum. %):			
	Max (Cum. %):			

TOTAL PARTICULATE EMISSION FACTOR: 5.5 kg particulate/Mg metal processed, before control. Emission factor from AP-42, Section 12.13. AP-42 gives an ESP control efficiency of 95 to 98.5%. At 95% efficiency, factor after ESP control is 0.275 kg particulate/Mg metal processed.

SOURCE OPERATION: Source produces steel castings by melting, alloying, and casting pig iron and steel scrap. During these tests, source was operating at 100% of rated capacity of 8260 kg metal scrap feed/hour, fuel oil-fired, and 8-hour heats.

SAMPLING TECHNIQUE: (a) Joy train with 3 cyclones (b) SASS train with cyclones

EMISSION FACTOR RATING: E

REFERENCE:

Emission test data from Environmental Assessment Data Systems, Fine Particle Emission Information System, Series Report No. 233, U. S. Environmental Protection Agency, Research Triangle Park, NC, June 1983.



Aerodynamic particle	Cumulative wt. 2 < stated size	Emission factor (kg/l0 ³ batteries)
diameter (um)	Uncontrolled	Uncontrolled
2.5	87.8	1.25
6.0	100	1.42
10.0	100	1.42

EMISSION FACTORS

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12.15 STORAGE BATTERY PRODUCTION: GRID CASTING

NUMBER OF TESTS: 3, conducted before control

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	87.8	100	100
	Standard deviation (Cum. %):	10.3	<u> </u>	_
	Min (Cum. %):	75.4	100	100
	Max (Cum. %):	100	100	100

Impactor cut points were so small that most data points had to be extrapolated.

TOTAL PARTICULATE EMISSION FACTOR: 1.42 kg particulate/10³ batteries produced, without controls. Factor from AP-42, Section 12.15.

SOURCE OPERATION: During tests, plant was operated at 39% of design process rate. Six of nine of the grid casting machines were operating during the test. Typically, 26,500 to 30,000 pounds of lead per 24-hour day are charged to the grid casting operation.

SAMPLING TECHNIQUE: Brink Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, Globe Union, Inc., Canby, OR, EMB-76-BAT-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1976.



Particle diameter, um

Aerodynamic particle	Cumulative wt. % < stated size	Emission factor (kg/10 ³ batteries)	
diameter (um)	Uncontrolled	Uncontrolled	
2.5	65.1	2.20	
6.0	90.4	3.05	
10.0	100	3.38	

12.15 STORAGE BATTERY PRODUCTION: GRID CASTING AND PASTE MIXING

NUMBER OF TESTS: 3, conducted before control

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	65.1	90.4	100
	Standard deviation (Cum. %):	24.8	7.4	-
	Min (Cum. %):	44.1	81.9	100
	Max (Cum. %):	100	100	100

TOTAL PARTICULATE EMISSION FACTOR: 3.38 kg particulate/ 10^3 batteries, without controls. Factor is from AP-42, Section 12.15, and is the sum of the individual factors for grid casting and paste mixing.

SOURCE OPERATION: During tests, plant was operated at 39% of the design process rate. Grid casting operation consists of 4 machines. Each 2,000 lb/hr paste mixer is controlled for product recovery by a separate low-energy, impingement-type wet collector designed for an 8 - 10 inch w. g. pressure drop at 2,000 acfm.

SAMPLING TECHNIQUE: Brink Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, Globe Union, Inc., Canby, OR, EMB-76-BAT-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1976.



Aerodynamic particle diameter (um)	Cumulative wt. Z < stated size After fabric filter	Emission factor (kg/10 ³ batteries) After fabric filter	: i
2.5	32.8	0.016	 : :
6.0	64.7	0.032	•
10.0	83.8	0.042	,

Particle diameter, um

12.15 STORAGE BATTERY PRODUCTION: LEAD OXIDE MILL

NUMBER OF TESTS: 3, conducted after fabric filter

STATISTICS:	Aerodynamic particle diameter (µm):	2.5	6.0	10.0
	Mean (Cum. %):	32.8	64.7	83.8
	Standard deviation (Cum. %):	14.1	29.8	19.5
	Min (Cum. %):	17.8	38.2	61.6
	Max (Cum. %):	45.9	97.0	100

TOTAL PARTICULATE EMISSION FACTOR: 0.05 kg particulate/ 10^3 batteries, after typical fabric filter control (oil-to-cloth ratio of 4:1). Emissions from a well-controlled facility (fabric filters with an average air-to-cloth ratio of 3:1) were 0.025 kg/ 10^3 batteries (Table 12.15-1 of AP-42).

SOURCE OPERATION: Plant receives metallic lead and manufactures lead oxide by the ball mill process. There are 2 lead oxide production lines, each with a typical feed rate of 15 100-pound lead pigs per hour. Product is collected with a cyclone and baghouses with 4:1 air-to-cloth ratios.

SAMPLING TECHNIQUE: Andersen Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, ESB Canada Limited, Mississouga, Ontario, EMB-76-BAT-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1976.



Aerodynamic	Cumulative wt.	<pre>< stated size</pre>	Emission factor	
particle diameter (um)	Uncontrolled	Fabric filter	(kg/10 ³ batteries) Uncontrolled	·
2.5	80	47	1.58	
6.0	100	87	1.96	
10.0	100	99	1.96	

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12.15 STORAGE BATTERY PRODUCTION: PASTE MIXING AND LEAD OXIDE CHARGING

NUMBER OF TESTS: (a) 1, conducted before control (b) 4, conducted after fabric filter control

STATISTICS:	(a)	erodynamic particle diameter (μ m): 2.5 6.0	10.0		
		Mean (Cum. %):	80	100	100
		Standard deviation (Cum. %):			
		Min (Cum. %):			
		Max (Cum. %):			
	(b)	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
(Mean (Cum. %.):	47	87	99
		Standard deviation (Cum. %):	33.4	14.5	0.9
		Min (Cum. %):	36	65	98
		Max (Cum. %):	100	100	100

Impactor cut points were so small that many data points had to be extrapolated. Reliability of particle size distributions based on a single test is questionable.

TOTAL PARTICULATE EMISSION FACTOR: 1.96 kg. particulate/10³ batteries, without controls. Factor from AP-42, Section 12.15.

SOURCE OPERATION: During test, plant was operated at 39% of the design process rate. Plant has normal production rate of 2,400 batteries per day and maximum capacity of 4,000 batteries per day. Typical amount of lead oxide charged to the mixer is 29,850 lb/8-hour shift. Plant produces wet batteries, except formation is carried out at another plant.

SAMPLING TECHNIQUE: (a) Brink Impactor (b) Andersen Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, Globe Union, Inc., Canby, OR, EMB-76-BAT-4, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1976.



Aerodynamic	Cumulative wt. X < stated size	Emission factor (kg/10 ³ batteries)
diameter (um)	Uncontroll ed	Uncontrolled
2.5	93.4	39.3
6.0	100	42
10.0	100	42

EMISSION FACTORS

12.15 STORAGE BATTERY PRODUCTION: THREE-PROCESS OPERATION

NUMBER OF TESTS: 3, conducted before control

STATISTICS:	Aerodynamic particle diameter (μ m):	2.5	6.0	10.0
	Mean (Cum. %):	93.4	100	100
	Standard deviation (Cum. %):	6.43		
	Min (Cum. %):	84.7		
	Max (Cum. %):	100		

Impactor cut points were so small that data points had to be extrapolated.

TOTAL PARTICULATE EMISSION FACTOR: 42 kg particulate/10³ batteries, before controls. Factor from AP-42, Section 12.15.

SOURCE OPERATION: Plant representative stated that the plant usually operated at 35% of design capacity. Typical production rate is 3,500 batteries per day (dry and wet), but up to 4,500 batteries per day can be produced. This is equivalent to normal and maximum daily element production of 21,000 and 27,000 battery elements, respectively.

SAMPLING TECHNIQUE: Brink Impactor

EMISSION FACTOR RATING: E

REFERENCE:

Air Pollution Emission Test, ESB Canada Limited, Mississouga, Ontario, EMB-76-BAT-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1976.





Aerodynamic	Cumulative wt. % < stated size	Emission factor, kg/Mg		
particle diameter, um	Uncontrolled	Uncontroll ed		
2.5	37.2	0.93		
6.0	45.9	1.15		
10.0	55.9	1.40		
10.0	55.9	1.40		

EMISSION FACTORS

12.xx BATCH TINNER

NUMBER OF TESTS: 2, conducted before controls

STATISTICS: Aerodynamic particle diameter (μ m): 2.5 6.0 10.0

Mean (Cum. %): 37.2 45.9 55.9 Standard deviation (Cum. %): Min (Cum. %): Max (Cum. %):

TOTAL PARTICULATE EMISSION FACTOR: 2.5 kg particulate/Mg tin consumed, without controls. Factor from AP-42, Section 12.14.

SOURCE OPERATION: Source is a batch operation applying a lead/tin coating to tubing. No further source operating information is available.

SAMPLING TECHNIQUE: Andersen Mark III Impactor

EMISSION FACTOR RATING: D

REFERENCE:

Confidential test data, PEI Associates, Inc., Golden, CO, January 1985.

APPENDIX B.2

GENERALIZED PARTICLE SIZE DISTRIBUTIONS

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Appendix B.2

Generalized Particle Size Distributions

B.2.1 Rationale For Developing Generalized Particle Size Distributions

The preparation of size-specific particulate emission inventories requires size distribution information for each process. Particle size distributions for many processes are contained in appropriate industry sections of this document. Because particle size information for many processes of local impact and concern are unavailable, this appendix provides "generic" particle size distributions applicable to these processes. The concept of the "generic" particle size distribution is based on categorizing measured particle size data from similar processes generating emissions from similar materials. These generic distributions have been developed from sampled size distributions from about 200 sources.

Generic particle size distributions are approximations. They should be used only in the absence of source-specific particle size distributions for areawide emission inventories.

B.2.2 How To Use The Generalized Particle Size Distributions For Uncontrolled Processes

Figure B.2-1 provides an example calculation to assist the analyst in preparing particle size-specific emission estimates using generic size distributions.

The following instructions for the calculation apply to each particulate emission source for which a particle size distribution is desired and for which no source specific particle size information is given elsewhere in this document:

- 1. Identify and review the AP-42 section dealing with that process.
- 2. Obtain the uncontrolled particulate emission factor for the process from the main text of AP-42, and calculate uncontrolled total particulate emissions.
- 3. Obtain the category number of the appropriate generic particle size distribution from Table B.2-1.
- 4. Obtain the particle size distribution for the appropriate category from Table B.2-2. Apply the particle size distribution to the uncontrolled particulate emissions.

Instructions for calculating the controlled size-specific emissions are given in Table B.2-3 and illustrated in Figure B.2-1.
Figure B.2-1. Example calculation for determining uncontrolled and controlled particle size-specific emissions.

SOURCE IDENTIFICATION

Source name and address:	ABC Brick Manufacturing
	24 Dusty Way
	Anywhere, USA

Process description:	Dryers/Grinders	
AP-42 Section:	8.3, Bricks And Related Clay Products	
Uncontrolled AP-42		
emission factor:	<u>96 lbs/ton</u>	(units)
Activity parameter:	63,700 tons/year	(units)
Uncontrolled emissions:	3057.6 tons/year	(units)

UNCONTROLLED SIZE EMISSIONS

Category nam	e: Mechanically	Generated/Aggregated,	Unprocessed Ores
Category num	ber: <u>3</u>		

	Particle size (µm)		
	≤ 2.5	≤ 6	≤ 10
Generic distribution, Cumulative percent equal to or less than the size:	15	34	51
Cumulative mass ≤ particle size emissions (tons/year):	458.6	1039.6	1559.4

CONTROLLED SIZE EMISSIONS*

Type of control device: Fabric Filter

	Particle size (µm)		
	0 - 2.5	2.5 - 6	6 - 10
Collection efficiency (Table B.2-3):	99.0	99.5	99.5
Mass in size range** before control (tons/year):	458.6	581.0	519.8
Mass in size range after control (tons/year):	4.59	2.91	2.60
Cumulative mass (tons/year):	4.59	7.50	10.10

* These data do not include results for the greater than 10 μ m particle size range.

****** Uncontrolled size data are cumulative percent equal to or less than the size. Control efficiency data apply only to size range and are not cumulative.

AP-42 AP-42 Category Category Section Number* Section Source Category Number* Source Category External combustion 8.5.3 Ammonium phosphates Bituminous and subbituminous coal Reactor/ammoniator-granulator 4 1.1 a combustion Dryer/cooler 4 Anthracite coal combustion 8.7 Hydrofluoric acid 1.2 a Spar drying 3 Fuel oil combustion 1.3 Residual oil Spar handling 3 3 Utility Transfer a 8.9 Phosphoric acid (thermal process) Commercial а а Sulfuric acid Distillate oil 8.10 b Sodium carbonate Utility а 8.12 a Commercial Food and agricultural a Defoliation and harvesting of cotton Residential 9.3.1 a Trailer loading Natural gas combustion 6 1.4 а Liquefied petroleum gas Transport б 1.5 a Wood waste combustion in boilers 9.3.2 Harvesting of grain 1.6 a Lignite combustion Harvesting machine 6 1.7 а 1.8 Bagasse combustion h Truck loading 6 Field transport 1.9 Residential fireplaces 6 a 9.5.2 Meat smokehouses 9 Residential wood stoves 1.10 a Waste oil combustion 9.7 Cotton ginning ь 1.11 я 9.9.1 Grain elevators and processing plants Solid waste disposal a 9.9.4 Alfalfa dehydrating 2.1 Refuse combustion a 2.2 Sewage sludge incineration а Primary cyclone b Conical burners (wood waste) 2 Meal collector cyclone 7 2.7 Pellet cooler cyclone 7 Internal combustion engines Pellet regrind cyclone 7 Highway vehicles c 7 3.2 Off highway vehicles 1 9.9.7 Starch manufacturing Organic chemical processes 9.12 Fermentation 6,7 6 Paint and varnish 4 9.13.2 Coffee roasting 6.4 Phthalic anhydride 9 Wood products 6.5 6.8 Soap and detergents а 10.2 Chemical wood pulping а 10.7 Charcoal Inorganic chemical processes Q 8.2 Urea Mineral products a 8.3 Ammonium nitrate fertilizers 11.1 Hot mix asphalt plants а а Ammonium sulfate 11.3 Bricks and related clay products 8.4 Rotary dryer b Raw materials handling Fluidized bed dryer b Dryers, grinders, etc. ь 8.5 3 Phosphate fertilizers

Table B.2-1. PARTICLE SIZE CATEGORY BY AP-42 SECTION

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				· • · · · · · · · · · · · · · · · · · ·	
AP-42 Sectior	Source Category	Category Number*	AP-42 Sectior	Source Category	Category Number*
	Tunnel/periodic kilns		11.16	Gypsum manufacturing	- 1
	Gas fired	a		Rotary ore dryer	a
	Oil fired	a		Roller mill	4
	Coal fired	a		Impact mill	4
11.5	Refractory manufacturing			Flash calciner	a
	Raw material dryer	3		Continuous kettle calciner	a
	Raw material crushing and screening	3	11.17	Lime manufacturing	a
	Electric arc melting	8	11.18	Mineral wool manufacturing	
	Curing oven	3		Cupola	8
11.6	Portland cement manufacturing			Reverberatory furnace	8
11.00	Dry process			Blow chamber	8
	Kilns	9		Curing oven	9
	Devers grinders etc	4		Cooler	9
	Wet process	-	11 10 1	Sand and gravel processing	
	Kilne	٩	14,17,4	Continuous drop	
		a 4		Transfor station	
	Dryers, grinders, etc.	4		D'h fransfer station	a
11.7	Ceramic clay manufacturing			Pile formation - stacker	a
	Drying	3		Batch drop	a
	Grinding	4		Active storage piles	a
11 0	Storage	3	11 10 2	Cryshed stone processing	a
11.8	Ely ach cintering or shine		11.19.2	Dry crushing	
	riy ash sincing, crushing,	5		Dry crushing Primary crushing	а
	Clay mixed with coke	5		Secondary crushing and screening	a
	Crushing, screening, yard storage	3		Tertiary crushing and screening	3
11.9	Western surface coal mining	а		Recrushing and screening	4
11.10	Coal cleaning	3		Fines mill	4
11.12	Concrete batching	3		Screening, conveying, handling	a
11.13	Glass fiber manufacturing		11.21	Phosphate rock processing	
	Unloading and conveying	3		Drying	а
	Storage bins	3		Calcining	а
	Mixing and weighing	3		Grinding	b
	Glass furnace - wool	а		Transfer and storage	3
	Glass furnace - textile	a	11.23	Taconite ore processing	
11.15	Glass manufacturing	a		Fine crushing	4

Table B.2-1 (cont.).

Table	B.2-1	(cont.).
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AP-42 Section	Source Category	Category Number*	AP-42 Section	Source Category	Category Number*
	Waste gas	a	12.7	Zinc smelting	8
	Pellet handling	4	12.8	Secondary aluminum operations	
	Grate discharge	5		Sweating furnace	8
	Grate feed	4		Smelting	
	Bentonite blending	4		Crucible furnace	8
	Coarse crushing	3		Reverberatory furnace	a
	Ore transfer	3	12.9	Secondary copper smelting	
	Bentonite transfer	4		and alloying	8
	Unpaved roads	a	12.10	Gray iron foundries	a
11.24	Metallic minerals processing	a	12.11	Secondary lead processing	a
	Metallurgical		12.12	Secondary magnesium smelting	8
12.1	Primary aluminum production		12.13	Steel foundries - melting	ь
	Bauxite grinding	4	12.14	Secondary zinc processing	8
	Aluminum hydroxide calcining	5	12.15	Storage battery production	ъ
	Anode baking furnace	9	12.18	Leadbearing ore crushing and grinding	4
	Prebake cell	а		Miscellaneous sources	
	Vertical Soderberg	8	13.1	Wildfires and prescribed burning	а
	Horizontal Soderberg	а	13.2	Fugitive dust	а
12.2	Coke manufacturing	а			
12.3	Primary copper smelting	a			
12.4	Ferroalloy production	а			
12.5	Iron and steel production				
	Blast furnace				
	Slips	a			
	Cast house	а			
	Sintering				
	Windbox	а			
	Sinter discharge	a			
	Basic oxygen furnace	a			
	Electric arc furnace	a			
12.6	Primary lead smelting	a			

* Data for numbered categories are given Table B.2-2. Particle size data on "a" categories are found in the AP-42 text; for "b" categories, in Appendix B.1; and for "c" categories, in AP-42 Volume II: Mobile Sources.

Figure B.2-2. CALCULATION SHEET

SOURCE IDENTIFICATIS Source name and address:	ION 	``````````````````````````````````````			
Process description: AP-42 Section: Uncontrolled AP-42 emission factor: Activity parameter: Uncontrolled emissions:					(units) (units) (units)
UNCONTROLLED SIZE Category name: Category number:	EMISSIONS				
				Particle size (μm)
			≤ 2.5	≤ 6	≤ 10
Generic distribution, Cum percent equal to or less t	ulative han the size:				
Cumulative mass ≤ partic (tons/year):	cle size emissions				
CONTROLLED SIZE EM Type of control device:	fISSIONS*				
				Particle size ((μm)
			0 - 2.5	2.5 - 6	6 - 10
Collection efficiency (Tab	le B.2-3):				
Mass in size range** befo (tons/year):	re control				
Mass in size range after c (tons/year):	ontrol				
Cumulative mass (tons/ye	ar):				

- * These data do not include results for the greater than 10 μ m particle size range.
- ** Uncontrolled size data are cumulative percent equal to or less than the size. Control efficiency data apply only to size range and are not cumulative.

Table B.2-2. DESCRIPTION OF PARTICLE SIZE CATEGORIES

Category:

Process:Stationary Internal Combustion EnginesMaterial:Gasoline and Diesel Fuel

Category 1 covers size-specific emissions from stationary internal combustion engines. The particulate emissions are generated from fuel combustion.

REFERENCES: 1,9

1



Particle Size, μm	Cumulative % ≤ Stated Size (Uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0 ^a	82			
2.0 ^a	88			
2.5	90	78	99	11
3.0 ^a	90			
4.0 ^a	92			
5.0 ^a	93			
6.0	93	86	99	7
10.0	96	92	99	4

Category:	2
Process:	Combustion
Material:	Mixed Fuels

Category 2 covers boilers firing a mixture of fuels, regardless of the fuel combination. The fuels include gas, coal, coke, and petroleum. Particulate emissions are generated by firing these miscellaneous fuels.

REFERENCE: 1



Particle Size, µm	Cumulative % ≤ Stated Size (Uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0 ^a	23			
2.0ª	40			
2.5	45	32	70	17
3.0ª	50			
4.0ª	58			
5.0ª	64			
6.0	70	49	84	14
10.0	79	56	87	12

Category:3Process:Mechanically GeneratedMaterial:Aggregate, Unprocessed Ores

Category 3 covers material handling and processing of aggregate and unprocessed ore. This broad category includes emissions from milling, grinding, crushing, screening, conveying, cooling, and drying of material. Emissions are generated through either the movement of the material or the interaction of the material with mechanical devices.

REFERENCES: 1-2,4,7



Particle Size, μm	Cumulative % ≤ Stated Size (Uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0 ^a	4			
2.0 ^a	11			
2.5	15	3	35	7
3.0 ^a	18			
4.0 ^a	25			
5.0 ^a	30			
6.0	34	15	65	13
10.0	51	23	81	14

Category:4Process:Mechanically GeneratedMaterial:Processed Ores and Nonmetallic Minerals

Category 4 covers material handling and processing of processed ores and minerals. While similar to Category 3, processed ores can be expected to have a greater size consistency than unprocessed ores. Particulate emissions are a result of agitating the materials by screening or transfer during size reduction and beneficiation of the materials by grinding and fine milling and by drying.



Particle Size, μm	Cumulative % ≤ Stated Size (Uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0 ^a	6			
2.0 ^a	21			
2.5	30	1	51	19
3.0 ^a	36			
4.0 ^a	48			
5.0 ^a	58			
6.0	62	17	83	17
10.0	85	70	93	7

Category:5Process:Calcining and Other Heat Reaction ProcessesMaterial:Aggregate, Unprocessed Ores

Category 5 covers the use of calciners and kilns in processing a variety of aggregates and unprocessed ores. Emissions are a result of these high temperature operations.

REFERENCES: 1-2,8



Particle Size, μm	Cumulative % ≤ Stated Size (Uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0 ^a	6			
2.0ª	13			
2.5	18	3	42	11
3.0ª	21			
4.0 ^a	28			
5.0 ^a	33			
6.0	37	13	74	19
10.0	53	25	84	19

Category: 6 Process: Grain Handling Material: Grain

Category 6 covers various grain handling (versus grain processing) operations. These processes could include material transfer, ginning and other miscellaneous handling of grain. Emissions are generated by mechanical agitation of the material.

REFERENCES: 1,5



Particle Size, μ m	Cumulative % ≤ Stated Size (Uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0 ^a	0.07			
2.0 ^a	0.60			
2.5	1	0	2	1
3.0 ^a	2			
4.0 ^a	3			
5.0 ^a	5			
6.0	7	3	12	3
10.0	15	6	25	7

^a Value calculated from data reported at 2.5, 6.0, and 10.0 μ m. No statistical parameters are given for the calculated value.

EMISSION FACTORS

Category: 7 Process: Grain Processing Material: Grain

Category 7 covers grain processing operations such as drying, screening, grinding, and milling. The particulate emissions are generated during forced air flow, separation, or size reduction.

REFERENCES: 1-2



			فتقاد المتشري يتدف التجاني والمتحد	
Particle Size, μm	Cumulative % ≤ Stated Size (Uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0 ^a	8			
2.0 ^a	18			
2.5	23	17	34	9
3.0 ^a	27			
4.0 ^a	34			
5.0 ^a	40			
6.0	43	35	48	7
10.0	61	56	65	5

Category:8Process:Melting, Smelting, RefiningMaterial:Metals, except Aluminum

Category 8 covers the melting, smelting, and refining of metals (including glass) other than aluminum. All primary and secondary production processes for these materials which involve a physical or chemical change are included in this category. Materials handling and transfer are not included. Particulate emissions are a result of high temperature melting, smelting, and refining.

REFERENCES: 1-2



Particle Size, µm	Cumulative % ≤ Stated Size (Uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0 ^a	72			
2.0ª	80			
2.5	82	63	99	12
3.0ª	84			
4.0 ^a	86			
5.0 ^a	88			
6.0	89	75	99	9
10.0	92	80	99	7

Category:9Process:Condensation, Hydration, Absorption, Prilling, and DistillationMaterial:All

Category 9 covers condensation, hydration, absorption, prilling, and distillation of all materials. These processes involve the physical separation or combination of a wide variety of materials such as sulfuric acid and ammonium nitrate fertilizer. (Coke ovens are included since they can be considered a distillation process which separates the volatile matter from coal to produce coke.)

REFERENCES: 1,3



Particle Size, μm	Cumulative % ≤ Stated Size (Uncontrolled)	Minimum Value	Maximum Value	Standard Deviation
1.0ª	60			
2.0ª	74			
2.5	78	59	99	17
3.0 ^a	81			
4.0 ^a	85			
5.0 ^a	88			
6.0	91	61	99	12
10.0	94	71	99	9

B.2.3 How To Use The Generalized Particle Size Distributions For Controlled Processes

To calculate the size distribution and the size-specific emissions for a source with a particulate control device, the user first calculates the uncontrolled size-specific emissions. Next, the fractional control efficiency for the control device is estimated using Table B.2-3. The Calculation Sheet provided (Figure B.2-2) allows the user to record the type of control device and the collection efficiencies from Table B.2-3, the mass in the size range before and after control, and the cumulative mass. The user will note that the uncontrolled size data are expressed in cumulative fraction less than the stated size. The control efficiency data apply only to the size range indicated and are not cumulative. These data do not include results for the greater than 10 μ m particle size range. In order to account for the total controlled emissions, particles greater than 10 μ m in size must be included.

B.2.4 Example Calculation

An example calculation of uncontrolled total particulate emissions, uncontrolled size-specific emissions, and controlled size specific emission is shown in Figure B.2-1. A blank Calculation Sheet is provided in Figure B.2-2.

Table B.2-3. TYPICAL COLLECTION EFFICIENCIES OF VARIOUS PARTICULATE
CONTROL DEVICES^a

(%)

AIRS		Pa	article Size (J	um)
Code ^b	Type Of Collector	0 - 2.5	2.5 - 6	6 - 10
001	Wet scrubber - hi-efficiency	90	95	99
002	Wet scrubber - med-efficiency	25	85	95
003	Wet scrubber - low-efficiency	20	80	90
004	Gravity collector - hi-efficiency	3.6	5	6
005	Gravity collector - med-efficiency	2.9	4	4.8
006	Gravity collector - low-efficiency	1.5	3.2	3.7
007	Centrifugal collector - hi-efficiency	80	95	95
800	Centrifugal collector - med-efficiency	50	75	85
009	Centrifugal collector - low-efficiency	10	35	50
010	Electrostatic precipitator - hi-efficiency	95	99	99.5
011	Electrostatic precipitator - med-efficiency boilers other	50 80	80 90	94 97
012	Electrostatic precipitator - low-efficiency boilers other	40 70	70 80	90 90
014	Mist eliminator - high velocity > 250 FPM	10	75	90
015	Mist eliminator - low velocity <250 FPM	5	40	75

EMISSION FACTORS

4175		Particle Size (µm)		um)
Code ^b	Type Of Collector	0 - 2.5	2.5 - 6	6 - 10
016	Fabric filter - high temperature	99	99.5	99.5
017	Fabric filter - med temperature	99	99. 5	99.5
018	Fabric filter - low temperature	99	99. 5	99.5
046	Process change	NA	NA	NA
049	Liquid filtration system	50	75	85
050	Packed-gas absorption column	90	95	99
051	Tray-type gas absorption column	25	85	95
052	Spray tower	20	80	90
053	Venturi scrubber	90	95	99
054	Process enclosed	1.5	3.2	3.7
055	Impingement plate scrubber	25	95	99
056	Dynamic separator (dry)	90	95	9 9
057	Dynamic separator (wet)	50	75	85
058	Mat or panel filter - mist collector	92	94	97
059	Metal fabric filter screen	10	15	20
061	Dust suppression by water sprays	40	65	90
062	Dust suppression by chemical stabilizer or wetting agents	40	65	90
063	Gravel bed filter	0	5	80
064	Annular ring filter	80	90	97
071	Fluid bed dry scrubber	10	20	90
075	Single cyclone	10	35	50
076	Multiple cyclone w/o fly ash reinjection	80	95	95
077	Multiple cyclone w/fly ash reinjection	50	75	85
085	Wet cyclonic separator	50	75	85
086	Water curtain	10	45	90

Table B.2-3 (cont.).

 ^a Data represent an average of actual efficiencies. Efficiencies are representative of well designed and well operated control equipment. Site-specific factors (e. g., type of particulate being collected, varying pressure drops across scrubbers, maintenance of equipment, etc.) will affect collection efficiencies. Efficiencies shown are intended to provide guidance for estimating control equipment performance when source-specific data are not available. NA = not applicable.

^b Control codes in Aerometric Information Retrieval System (AIRS), formerly National Emissions Data Systems. References For Appendix B.2

- 1. Fine Particle Emission Inventory System, Office Of Research And Development, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1985.
- 2. Confidential test data from various sources, PEI Associates, Inc., Cincinnati, OH, 1985.
- 3. Final Guideline Document: Control Of Sulfuric Acid Production Units, EPA-450/2-77-019, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1977.
- 4. Air Pollution Emission Test, Bunge Corp., Destrehan, LA, EMB-74-GRN-7, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1974.
- 5. I. W. Kirk, "Air Quality In Saw And Roller Gin Plants", Transactions Of The ASAE, 20:5, 1977.
- 6. Emission Test Report, Lightweight Aggregate Industry. Galite Corp., EMB- 80-LWA-6, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1982.
- Air Pollution Emission Test, Lightweight Aggregate Industry, Texas Industries, Inc., EMB-80-LWA-3, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1975.
- 8. Air Pollution Emission Test, Empire Mining Company, Palmer, Michigan, EMB-76-IOB-2, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1975.
- 9. H. J. Taback, et al., Fine Particulate Emissions From Stationary Sources In The South Coast Air Basin, KVB, Inc., Tustin, CA, 1979.
- K. Rosbury, Generalized Particle Size Distributions For Use In Preparing Particle Size-Specific Emission Inventories, U. S. EPA Contract No. 68-02-3890, PEI Associates, Inc., Golden, CO, 1985.

APPENDIX C.1

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PROCEDURES FOR SAMPLING SURFACE/BULK DUST LOADING

Appendix C.1

Procedures For Sampling Surface/Bulk Dust Loading

This appendix presents procedures recommended for the collection of material samples from paved and unpaved roads and from bulk storage piles. (AP-42, Appendix C.2, "Procedures For Laboratory Analysis Of Surface/Bulk Dust Loading Samples", presents analogous information for the analysis of the samples.) These recommended procedures are based on a review of American Society For Testing And Materials (ASTM) methods, such as C-136 (sieve analysis) and D-2216 (moisture content). The recommendations follow ASTM standards where practical, and where not, an effort has been made to develop procedures consistent with the intent of the pertinent ASTM standards.

This appendix emphasizes that, before starting any field sampling program, one must first define the study area of interest and then determine the number of samples that can be collected and analyzed within the constraints of time, labor, and money available. For example, the study area could be defined as an individual industrial plant with its network of paved/unpaved roadways and material piles. In that instance, it is advantageous to collect a separate sample for each major dust source in the plant. This level of resolution is useful in developing cost-effective emission reduction plans. On the other hand, if the area of interest is geographically large (say a city or county, with a network of public roads), collecting at least 1 sample from each source would be highly impractical. However, in such an area, it is important to obtain samples representative of different source types within the area.

C.1.1 Samples From Unpaved Roads

Objective -

The overall objective in an unpaved road sampling program is to inventory the mass of particulate matter (PM) emissions from the roads. This is typically done by:

- 1. Collecting "representative" samples of the loose surface material from the road;
- 2. Analyzing the samples to determine silt fractions; and
- 3. Using the results in the predictive emission factor model given in AP-42, Section 13.2.2, Unpaved Roads, together with traffic data (e. g., number of vehicles traveling the road each day).

Before any field sampling program, it is necessary to define the study area of interest and to determine the number of unpaved road samples that can be collected and analyzed within the constraints of time, labor, and money available. For example, the study area could be defined as a very specific industrial plant having a network of roadways. Here it is advantageous to collect a separate sample for each major unpaved road in the plant. This level of resolution is useful in developing cost-effective emission reduction plans involving dust suppressants or traffic rerouting. On the other hand, the area of interest may be geographically large, and well-defined traffic information may not be easily obtained. In this case, resolution of the PM emission inventory to specific road segments would not be feasible, and it would be more important to obtain representative road-type samples within the area by aggregating several sample increments.

Procedure -

For a network consisting of many relatively short roads contained in a *well-defined study area* (as would be the case at an industrial plant), it is recommended that one collect a sample for each 0.8 kilometers (km) (0.5 miles [mi]) length, or portion thereof, for each major road segment. Here,

the term "road segment" refers to the length of road between intersections (the nodes of the network) with other paved or unpaved roads. Thus, for a major segment $1 \text{ km} (0.6 \text{ mi}) \log_2 2 \text{ samples are recommended.}$

For longer roads in study areas that are spatially diverse, it is recommended that one collect a sample for each 4.8 km (3 mi) length of the road. Composite a sample from a minimum of 3 incremental samples. Collect the first sample increment at a random location within the first 0.8 km (0.5 mi), with additional increments taken from each remaining 0.8 km (0.5 mi) of the road, up to a maximum length of 4.8 km (3 mi). For a road less than 1.5 mi in length, an acceptable method for selecting sites for the increments is based on drawing 3 random numbers (x1, x2, x3) between zero and the length. Random numbers may be obtained from tabulations in statistical reference books, or scientific calculators may be used to generate pseudorandom numbers. See Figure C.1-1.

The following steps describe the collection method for samples (increments).

- 1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use 1 person to "spot" and route traffic safely around another person collecting the surface sample (increment).
- 2. Using string or other suitable markers, mark a 0.3 meters (m) (1 foot [ft]) wide portion across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.)
- 3. With a whisk broom and dustpan, remove the loose surface material from the hard road base. Do not abrade the base during sweeping. Sweeping should be performed slowly so that fine surface material is not injected into the air. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i. e., not from berms or any "mounds" along the road centerline).
- 4. Periodically deposit the swept material into a clean, labeled container of suitable size, such as a metal or plastic 19 liter (L) (5 gallon [gal]) bucket, having a sealable polyethylene liner. Increments may be mixed within this container.
- 5. Record the required information on the sample collection sheet (Figure C.1-2).

Sample Specifications -

For uncontrolled unpaved road surfaces, a gross sample of 5 kilograms (kg) (10 pounds [lb]) to 23 kg (50 lb) is desired. Samples of this size will require splitting to a size amenable for analysis (see Appendix C.2). For unpaved roads having been treated with chemical dust suppressants (such as petroleum resins, asphalt emulsions, etc.), the above goal may not be practical in well-defined study areas because a very large area would need to be swept. In general, a minimum of 400 grams (g) (1 lb) is required for silt and moisture analysis. Additional increments should be taken from heavily controlled unpaved surfaces, until the minimum sample mass has been achieved.

C.1.2 Samples From Paved Roads

Objective -

The overall objective in a paved road sampling program is to inventory the mass of particulate emissions from the roads. This is typically done by:

EMISSION FACTORS



Appendix C.1

SAMPLING DATA FOR UNPAVED ROADS

Date Collected	Recorded by
Road Material (e.g., gravel, slag, dirt, etc.):*	
Site of Sampling:	

METHOD:

- 1. Sampling device: whisk broom and dustpan
- 2. Sampling depth: loose surface material (do not abrade road base)
- 3. Sample container: bucket with sealable liner
- 4. Gross sample specifications:
 - a. Uncontrolled surfaces -- 5 kg (10 lb) to 23 kg (50 lb)
 - b. Controlled surfaces -- minimum of 400 g (1 lb) is required for analysis

Refer to AP-42 Appendix B.1 for more detailed instructions.

Indicate any deviations from the above: _____

SAMPLING DATA COLLECTED:

Sample No.	Time	Location +	Surf. Area	Depth	Mass of Sample
		الاست المستقي الماري المستقد والمستقد المستقد المستقد المستقد المستقد المستقد المستقد المستقد المستقد المستقد ا			

- * Indicate and give details if roads are controlled.
- + Use code given on plant or road map for segment identification. Indicate sampling location on map.

Figure C.1-2. Example data form for unpaved road samples.

- 1. Collecting "representative" samples of the loose surface material from the road;
- 2. Analyzing the sample to determine the silt fraction; and
- 3. Combining the results with traffic data in a predictive emission factor model.

The remarks above about definition of the study area and the appropriate level of resolution for sampling unpaved roads are equally applicable to paved roads. Before a field sampling program, it is necessary first to define the study area of interest and then to determine the number of paved road samples that can be collected and analyzed. For example, in a well-defined study area (e. g., an industrial plant), it is advantageous to collect a separate sample for each major paved road, because the resolution can be useful in developing cost-effective emission reduction plans. Similarly, in geographically large study areas, it may be more important to obtain samples representative of road types within the area by aggregating several sample increments.

Compared to unpaved road sampling, planning for a paved road sample collection exercise necessarily involves greater consideration as to types of equipment to be used. Specifically, provisions must be made to accommodate the characteristics of the vacuum cleaner chosen. For example, paved road samples are collected by cleaning the surface with a vacuum cleaner with "tared" (i. e., weighed before use) filter bags. Upright "stick broom" vacuums use relatively small, lightweight filter bags, while bags for industrial-type vacuums are bulky and heavy. Because the mass collected is usually several times greater than the bag tare weight, uprights are thus well suited for collecting samples from lightly loaded road surfaces. On the other hand, on heavily loaded roads, the larger industrial-type vacuum bags are easier to use and can be more readily used to aggregate incremental samples from all road surfaces. These features are discussed further below.

Procedure -

For a network of many relatively short roads contained in a well-defined study area (as would be the case at an industrial plant), it is recommended that one collect a sample for each 0.8 km (0.5 mi) length, or portion thereof, for each major road segment. For a 1 km long (0.6 mi) segment, then, 2 samples are recommended. As mentioned, the term "road segment" refers to the length of road between intersections with other paved or unpaved roads (the nodes of the network).

For longer roads in spatially heterogeneous study areas, it is recommended that one collect a sample for each 4.8 km (3 mi) of sampled road length. Create a composite sample from a minimum of 3 incremental samples. Collect the first increment at a random location within the first 0.8 km (0.5 mi), with additional increments taken from each remaining 0.8 km (0.5 mi) of the road, up to a maximum length of 4.8 km (3 mi.) For a road less than 2.4 km (1.5 mi) long, an acceptable method for selecting sites for the increments is based on drawing 3 random numbers (x1, x2, x3) between zero and the length (See Figure C.1-3). Random numbers may be obtained from tabulations in statistical reference books, or scientific calculators may be used to generate pseudorandom numbers.

The following steps describe the collection method for samples (increments).

- 1. Ensure that the site offers an unobstructed view of traffic and that sampling personnel are visible to drivers. If the road is heavily traveled, use 1 crew member to "spot" and route traffic safely around another person collecting the surface sample (increment).
- Using string or other suitable markers, mark the sampling portion across the road. (WARNING: Do not mark the collection area with a chalk line or in any other method likely to introduce fine material into the sample.) The widths may be varied between
 0.3 m (1 ft) for visibly dirty roads and 3 m (10 ft) for clean roads. When an industrial-



type vacuum is used to sample lightly loaded roads, a width greater than 3 m (10 ft) may be necessary to meet sample specifications, unless increments are being combined.

- 3. If large, loose material is present on the surface, it should be collected with a whisk broom and dustpan. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i. e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line" (but avoid centerline mounds). Store the swept material in a clean, labeled container of suitable size, such as a metal or plastic 19 L (5 gal) bucket, with a sealable polyethylene liner. Increments for the same sample may be mixed within the container.
- 4. Vacuum the collection area using a portable vacuum cleaner fitted with an empty tared (preweighed) filter bag. NOTE: Collect material only from the portion of the road over which the wheels and carriages routinely travel (i. e., not from berms or any "mounds" along the road centerline). On roads with painted side markings, collect material "from white line to white line" (but avoid centerline mounds). The same filter bag may be used for different increments for 1 sample. For heavily loaded roads, more than 1 filter bag may be needed for a sample (increment).
- 5. Carefully remove the bag from the vacuum sweeper and check for tears or leaks. If necessary, reduce samples (using the procedure in Appendix C.2) from broom sweeping to a size amenable to analysis. Seal broom-swept material in a clean, labeled plastic jar for transport (alternatively, the swept material may be placed in the vacuum filter bag). Fold the unused portion of the filter bag, wrap a rubber band around the folded bag, and store the bag for transport.
- 6. Record the required information on the sample collection sheet (Figure C.1-4).

Sample Specifications -

When broom swept samples are collected, they should be at least 400 g (1 lb) for silt and moisture analysis. Vacuum swept samples should be at least 200 g (0.5 lb). Also, the weight of an "exposed" filter bag should be at least 3 to 5 times greater than when empty. Additional increments should be taken until these sample mass goals have been attained.

C.1.3 Samples From Storage Piles

Objective -

The overall objective of a storage pile sampling and analysis program is to inventory particulate matter emissions from the storage and handling of materials. This is done typically by:

- 1. Collecting "representative" samples of the material;
- 2. Analyzing the samples to determine moisture and silt contents; and
- 3. Combining analytical results with material throughput and meteorological information in an emission factor model.

As initial steps in storage pile sampling, it is necessary to decide (a) what emission mechanisms - material load-in to and load-out from the pile, wind erosion of the piles - are of interest, and (b) how many samples can be collected and analyzed, given time and monetary constraints. (In general, annual average PM emissions from material handling can be expected to be

t2

SAMPLING DATA FOR PAVED ROADS

Date Collected	Recorded by
Sampling location *	No. of Lanes
Surface type (e.g., asphalt, concrete, etc.)	
Surface condition (e.g., good, rutted, etc.)	
 Use code given on plant or road map for segment ide location on map. 	entification. Indication sampling

METHOD:

- 1. Sampling device: portable vacuum cleaner (whisk broom and dustpan if heavy loading present)
- 2. Sampling depth: loose surface material (do not sample curb areas or other untravelled portions of the road)
- 3. Sample container: tared and numbered vacuum cleaner bags (bucket with sealable liner if heavy loading present)
- Gross sample specifications: Vacuum swept samples should be at least 200 g (0.5 lb), with the exposed filter bag weight should be at least 3 to 5 times greater than the empty bag tare weight.

Refer to AP-42 Appendix C.1 for more detailed instructions.

Indicate any deviations from the above: _____

SAMPLING DATA COLLECTED:

rpling face Mass of	Sampling Surface	Vacuum Bag		
nsions Broom-Swept < w) Time Sample +	Dimensions (I x w)	Tare Wgt (g)	ID	Sample No.
			<u></u>	
			<u> </u>	
	<u></u>		<u> </u>	

+ Enter "0" if no broom sweeping is performed.

..

Figure C.1-4. Example data form for paved roads.

EMISSION FACTORS

much greater than those from wind erosion.) For an industrial plant, it is recommended that at least 1 sample be collected for each major type of material handled within the facility.

In a program to characterize load-in emissions, representative samples should be collected from material recently loaded into the pile. Similarly, representative samples for load-out emissions should be collected from areas that are worked by load-out equipment such as front end loaders or clamshells. For most "active" piles (i. e., those with frequent load-in and load-out operations), 1 sample may be considered representative of both loaded-in and loaded-out materials. Wind erosion material samples should be representative of the surfaces exposed to the wind.

In general, samples should consist of increments taken from all exposed areas of the pile (i. e., top, middle, and bottom). If the same material is stored in several piles, it is recommended that piles with at least 25 percent of the amount in storage be sampled. For large piles that are common in industrial settings (e. g., quarries, iron and steel plants), access to some portions may be impossible for the person collecting the sample. In that case, increments should be taken no higher than it is practical for a person to climb carrying a shovel and a pail.

Procedure -

The following steps describe the method for collecting samples from storage piles:

- 1. Sketch plan and elevation views of the pile. Indicate if any portion is not accessible. Use the sketch to plan where the N increments will be taken by dividing the perimeter into N-1 roughly equivalent segments.
 - a. For a large pile, collect a minimum of 10 increments, as near to mid-height of the pile as practical.
 - b. For a small pile, a sample should be a minimum of 6 increments, evenly distributed among the top, middle, and bottom.

"Small" or "large" piles, for practical purposes, may be defined as those piles which can or cannot, respectively, be scaled by a person carrying a shovel and pail.

- Collect material with a straight-point shovel or a small garden spade, and store the increments in a clean, labeled container of suitable size (such as a metal or plastic 19 L [5 gal] bucket) with a sealable polyethylene liner. Depending upon the ultimate goals of the sampling program, choose 1 of the following procedures:
 - a. To characterize emissions from *material handling operations at an active pile*, take increments from the portions of the pile which most recently had material added and removed. Collect the material with a shovel to a depth of 10 to 15 centimeters (cm) (4 to 6 inches [in]). Do not deliberately avoid larger pieces of aggregate present on the surface.
 - b. To characterize *handling emissions from an inactive pile*, obtain increments of the core material from a 1 m (3 ft) depth in the pile. A sampling tube 2 m (6 ft) long, with a diameter at least 10 times the diameter of the largest particle being sampled, is recommended for these samples. Note that, for piles containing large particles, the diameter recommendation may be impractical.

c. If characterization of *wind erosion*, rather than material handling is the goal of the sampling program, collect the increments by skimming the surface in an upwards direction. The depth of the sample should be 2.5 cm (1 in), or the diameter of the largest particle, whichever is less. Do not deliberately avoid collecting larger pieces of aggregate present on the surface.

In most instances, collection method "a" should be selected.

3. Record the required information on the sample collection sheet (Figure C.1-5). Note the space for deviations from the summarized method.

Sample Specifications -

For any of the procedures, the sample mass collected should be at least 5 kg (10 lb). When most materials are sampled with procedures 2a or 2b, 10 increments will normally result in a sample of at least 23 kg (50 lb). Note that storage pile samples usually require splitting to a size more amenable to laboratory analysis. SAMPLING DATA FOR STORAGE PILES

Date Co	ollected Re	corded by
Type of	f material sampled	
Samplin	ng location*	
METHO	DD:	
1. 9	Sampling device: pointed shovel (hollow sampling tube if inact sampled)	ve pile is to be
2. \$ 	Sampling depth: For material handling of active piles: 10-15 cm (4-6 in.) For material handling of inactive piles: 1 m (3 ft) For wind erosion samples: 2.5 cm (1 in.) or depth of the larges is less)	t particle (whichever
3. 9 4. 0 1	Sample container: bucket with sealable liner Gross sample specifications: For material handling of active or inactive piles: minimum of 6 total sample weight of 5 kg (10 lb) [10 increments totalling 23 recommended] For wind erosion samples: minimum of 6 increments with tota 5 kg (10 lb)	increments with kg (50 lb) are I sample weight of

Refer to AP-42 Appendix C.1 for more detailed instructions.

Indicate any deviations from the above: _____

SAMPLING DATA COLLECTED:

Sample No.	Time	Location* of Sample Collection	Device Used S/T **	Depth	Mass of Sample
		·····			

Use code given of plant or area map for pile/sample identification. Indicate each
 sampling location on map.

** Indicate whether shovel or tube.

Figure C.1-5. Example data form for storage piles.

APPENDIX C.2

PROCEDURES FOR LABORATORY ANALYSIS OF SURFACE/BULK DUST LOADING SAMPLES

Appendix C.2

Procedures For Laboratory Analysis Of Surface/Bulk Dust Loading Samples

This appendix discusses procedures recommended for the analysis of samples collected from paved and unpaved surfaces and from bulk storage piles. (AP-42 Appendix C.1, "Procedures For Sampling Surface/Bulk Dust Loading", presents procedures for the collection of these samples.) These recommended procedures are based on a review of American Society For Testing And Materials (ASTM) methods, such as C-136 (sieve analysis) or D-2216 (moisture content). The recommendations follow ASTM standards where practical, and where not, an effort has been made to develop procedures consistent with the intent of the pertinent ASTM standards.

C.2.1 Sample Splitting

Objective -

The collection procedures presented in Appendix C.1 can result in samples that need to be reduced in size before laboratory analysis. Samples are often unwieldy, and field splitting is advisable before transporting the samples.

The size of the laboratory sample is important. Too small a sample will not be representative, and too much sample will be unnecessary as well as unwieldy. Ideally, one would like to analyze the entire gross sample in batches, but that is not practical. While all ASTM standards acknowledge this impracticality, they disagree on the exact optimum size, as indicated by the range of recommended samples, extending from 0.05 to 27 kilograms (kg) (0.1 to 60 pounds [lb]).

Splitting a sample may be necessary before a proper analysis. The principle in sizing a laboratory sample for silt analysis is to have sufficient coarse and fine portions both to be representative of the material and to allow sufficient mass on each sieve to assure accurate weighing. A laboratory sample of 400 to 1,600 grams (g) is recommended because of the capacity of normally available scales (1.6 to 2.6 kg). A larger sample than this may produce "screen blinding" for the 20 centimeter (cm) (8 inch [in.]) diameter screens normally available for silt analysis. Screen blinding can also occur with small samples of finer texture. Finally, the sample mass should be such that it can be spread out in a reasonably sized drying pan to a depth of < 2.5 cm (1 in.).

Two methods are recommended for sample splitting: riffles, and coning and quartering. Both procedures are described below.

Procedures -

Figure C.2-1 shows 2 riffles for sample division. Riffle slot widths should be at least 3 times the size of the largest aggregate in the material being divided. The following quote from ASTM Standard Method D2013-72 describes the use of the riffle.

Divide the gross sample by using a riffle. Riffles properly used will reduce sample variability but cannot eliminate it. Riffles are shown in Figure C.2-1. Pass the material through the riffle from a feed scoop, feed bucket, or riffle pan having a lip or opening the full length of the riffle. When using any of the above containers to feed the riffle, spread the material evenly in the container, raise the container, and hold it with its front edge resting on top of the feed chute, then slowly tilt it so that the material flows in a uniform stream through the hopper straight down over the center of the riffle into all the slots, thence into the riffle pans, one-half of the sample being collected in a pan.



Figure C.2-1. Sample riffle dividers.



Figure C.2-2. Procedure for coning and quartering.

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Under no circumstances shovel the sample into the riffle, or dribble into the riffle from a smallmouthed container. Do not allow the material to build up in or above the riffle slots. If it does not flow freely through the slots, shake or vibrate the riffle to facilitate even flow.¹

Coning and quartering is a simple procedure useful with all powdered materials and with sample sizes ranging from a few grams to several hundred pounds.² Oversized material, defined as > 0.6 millimeters (mm) (3/8 in.) in diameter, should be removed before quartering and be weighed in a "tared" container (one for which its empty weight is known).

Preferably, perform the coning and quartering operation on a floor covered with clean 10 mil plastic. Take care that the material is not contaminated by anything on the floor or that any portion is not lost through cracks or holes. Samples likely affected by moisture or drying must be handled rapidly, preferably in a controlled atmosphere, and sealed in a container to prevent further changes during transportation and storage.

The procedure for coning and quartering is illustrated in Figure C.2-2. The following procedure should be used:

- 1. Mix the material and shovel it into a neat cone.
- 2. Flatten the cone by pressing the top without further mixing.
- 3. Divide the flat circular pile into equal quarters by cutting or scraping out 2 diameters at right angles.
- 4. Discard 2 opposite quarters.
- 5. Thoroughly mix the 2 remaining quarters, shovel them into a cone, and repeat the quartering and discarding procedures until the sample is reduced to 0.4 to 1.8 kg (1 to 4 lb).

C.2.2 Moisture Analysis

Paved road samples generally are not to be oven dried because vacuum filter bags are used to collect the samples. After a sample has been recovered by dissection of the bag, it is combined with any broom swept material for silt analysis. All other sample types are oven dried to determine moisture content before sieving.

Procedure -

- 1. Heat the oven to approximately 110°C (230°F). Record oven temperature. (See Figure C.2-3.)
- 2. Record the make, capacity, and smallest division of the scale.
- 3. Weigh the empty laboratory sample containers which will be placed in the oven to determine their tare weight. Weigh any lidded containers with the lids. Record the tare weight(s). Check zero before each weighing.
- 4. Weigh the laboratory sample(s) in the container(s). For materials with high moisture content, assure that any standing moisture is included in the laboratory sample container. Record the combined weight(s). Check zero before each weighing.

MOISTURE ANALYSIS

Date:	Ву:		
Sample No:	Oven Temperature:		
Material:	Date In:Date Out:		
	Time In:Time Out:		
Split Sample Balance:	Drying Time:		
Make	_		
Capacity	Sample Weight (after drying)		
Smallest division	Pan + Sample:		
	Pan:		
Total Sample Weight:	Dry Sample:		
(Excl. Container)			
Number of Splits:	MOISTURE CONTENT:		
	(A) Wet Sample Wt.		
Split Sample Weight (before drying)	(B) Dry Sample Wt		
Pan + Sample:	(C) Difference Wt.		
Pan:	<u>C x 100</u>		
Wet Sample:	A = % Moisture		

Figure C.2-3. Example moisture analysis form.

- 5. Place sample in oven and dry overnight. Materials composed of hydrated minerals or organic material such as coal and certain soils should be dried for only 1.5 hours.
- 6. Remove sample container from oven and (a) weigh immediately if uncovered, being careful of the hot container; or (b) place a tight-fitting lid on the container and let it cool before weighing. Record the combined sample and container weight(s). Check zero before weighing.
- 7. Calculate the moisture, as the initial weight of the sample and container, minus the ovendried weight of the sample and container, divided by the initial weight of the sample alone. Record the value.
- 8. Calculate the sample weight to be used in the silt analysis, as the oven-dried weight of the sample and container, minus the weight of the container. Record the value.

C.2.3 Silt Analysis

Objective -

Several open dust emission factors have been found to be correlated with the silt content (< 200 mesh) of the material being disturbed. The basic procedure for silt content determination is mechanical, dry sieving. For sources other than paved roads, the same sample which was oven-dried to determine moisture content is then mechanically sieved.

For paved road samples, the broom-swept particles and the vacuum-swept dust are individually weighed on a beam balance. The broom-swept particles are weighed in a container, and the vacuum-swept dust is weighed in the bag of the vacuum, which was tared before sample

EMISSION FACTORS

collection. After weighing the sample to calculate total surface dust loading on the traveled lanes, combine the broom-swept particles and the vacuumed dust. Such a composite sample is usually small and may not require splitting in preparation for sieving.

Procedure -

- Select the appropriate 20-cm (8-in.) diameter, 5-cm (2-in.) deep sieve sizes. Recommended U. S. Standard Series sizes are 3/8 in., No. 4, No. 40, No. 100, No. 140, No. 200, and a pan. Comparable Tyler Series sizes can also be used. The No. 20 and the No. 200 are mandatory. The others can be varied if the recommended sieves are not available, or if buildup on 1 particulate sieve during sieving indicates that an intermediate sieve should be inserted.
- 2. Obtain a mechanical sieving device, such as a vibratory shaker or a Roto-Tap[®] without the tapping function.
- 3. Clean the sieves with compressed air and/or a soft brush. Any material lodged in the sieve openings or adhering to the sides of the sieve should be removed, without handling the screen roughly, if possible.
- 4. Obtain a scale (capacity of at least 1600 grams [g] or 3.5 lb) and record make, capacity, smallest division, date of last calibration, and accuracy. (See Figure C.2-4.)
- 5. Weigh the sieves and pan to determine tare weights. Check the zero before every weighing. Record the weights.
- 6. After nesting the sieves in decreasing order of size, and with pan at the bottom, dump dried laboratory sample (preferably immediately after moisture analysis) into the top sieve. The sample should weigh between ~ 400 and 1600 g (~ 0.9 and 3.5 lb). This amount will vary for finely textured materials, and 100 to 300 g may be sufficient when 90% of the sample passes a No. 8 (2.36 mm) sieve. Brush any fine material adhering to the sides of the container into the top sieve and cover the top sieve with a special lid normally purchased with the pan.
- 7. Place nested sieves into the mechanical sieving device and sieve for 10 minutes (min). Remove pan containing minus No. 200 and weigh. Repeat the sieving at 10-min intervals until the difference between 2 successive pan sample weighings (with the pan tare weight subtracted) is less than 3.0%. Do not sieve longer than 40 min.
- 8. Weigh each sieve and its contents and record the weight. Check the zero before every weighing.
- 9. Collect the laboratory sample. Place the sample in a separate container if further analysis is expected.
- 10. Calculate the percent of mass less than the 200 mesh screen (75 micrometers $[\mu m]$). This is the silt content.

SILT ANALYSIS

Date:	

Sample No):
Material:	

Make	
Smallest Division	

Ву:
Sample Weight (after drying) Pan + Sample:
Split Sample Balance:
Capacity:
Final Weight: <u>Net Weight < 200 Mesh</u>
% Silt = Total Net Weight x 100 =%

SIEVING

Time: Start:	Weight (Pan Only)
Initial (Tare):	
10 min:	
20 min:	
30 min:	
40 min:	

Screen	Tare Weight (Screen)	Final Weight (Screen + Sample)	Net Weight (Sample)	%
3/8 in.				
4 mesh				
10 mesh				
20 mesh				
40 mesh				
100 mesh				
140 mesh				
200 mesh				
Pan				

Figure C.2-4. Example silt analysis form.
References For Appendix C.2

- 1. "Standard Method Of Preparing Coal Samples For Analysis", Annual Book Of ASTM Standards, 1977, D2013-72, American Society For Testing And Materials, Philadelphia, PA, 1977.
- 2. L. Silverman, et al., Particle Size Analysis In Industrial Hygiene, Academic Press, New York, 1971.

TECHNICAL REPORT DATA

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6 ABSTRACT

This document contains emission factors and process information for more than 200 air pollution source categories. These emission factors have been compiled from source test data, material balance studies, and engineering estimates, and hey can be used judiciously in making emission estimations for various purposes. When specific source test data are available, they should be preferred over the generalized factors presented in this document.

This Supplement to AP-42 addresses pollutant-generating activity from Bituminous And Subbituminous Coal Combustion; Anthracite Coal Combustion; Fuel Oil Combustion; Natural Gas combustion; Wood Waste Combustion In 30ilers; Lignite Combustion; Waste Oil Combustion: Stationary Gas Turbines For Electricity Generation; Heavy-duty Natural Gas-fired Pipeline Compressor Engines; Large Stationary Diesel And All Stationary Dual-fuel Engines; Natural Gas Processing; Organic Liquid Storage Tanks; Meat Smokehouses; Meat Rendering Plants; Canned Fruits And Vegetables; Dehydrated Fruits And Vegetables; Pickles, Sauces And Salad Dressings; Grain Elevators And Processes; Cereal Breakfast Foods; Pasta Manufacturing; Vegetable Oil Processing; Wines And Brandy; Coffee Roasting; Charcoal; Coal Cleaning; Frit Manufacturing; Sand And Gravel Processing; Diatomite Processing; Talc Processing; Vermiculite Processing; Paved Roads; and Unpaved Roads. Also included is information on Generalized Particle Size Distributions.

7 KEY WORDS AND DOCUMENT ANALYSIS				
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