SUPPLEMENT NO. 6
FOR
COMPILATION
OF AIR POLLUTANT
EMISSION FACTORS

SECOND EDITION

U.S. ENVIRONMENTAL PROTECTION AGENCY
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INSTRUCTIONS
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PREFACE

This document reports data available on those atmospheric emissions for which sufficient information exists to establish realistic emission factors. The information contained herein is based on Public Health Service Publication 999-AP-42, *Compilation of Air Pollutant Emission Factors*, by R.L. Duprey, and on two revised and expanded editions of *Compilation of Air Pollutant Emission Factors* that were published by the Environmental Protection Agency in February 1972 and April 1973, respectively. This document is a reprint of the second edition and includes the supplements issued in July 1973, September 1973, July 1974, January 1975, and December 1975 (See page iv). It contains no new information not already presented in the previous issuances.

Chapters and sections of this document have been arranged in a format that permits easy and convenient replacement of material as information reflecting more accurate and refined emission factors is published and distributed. To speed dissemination of emission information, chapters or sections that contain new data will be issued—separate from the parent report—whenever they are revised.

To facilitate the addition of future materials, the punched, loose-leaf format was selected. This approach permits the document to be placed in a three-ring binder or to be secured by rings, rivets, or other fasteners; future supplements or revisions can then be easily inserted. The lower left- or right-hand corner of each page of the document bears a notation that indicates the date the information was issued.

The availability of future supplements to *Compilation of Air Pollutant Emission Factors* will be announced in the publication *Air Pollution Technical Publications of the Environmental Protection Agency*, which is available from the Air Pollution Technical Information Center, Research Triangle Park, N.C. 27711 (Telephone: 919—549-8411 ext. 2753). This listing of publications, normally issued in January and July, contains instructions for obtaining the desired supplements.

Comments and suggestions regarding this document should be directed to the attention of Director, Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, Environmental Protection Agency, Research Triangle Park, N.C. 27711.

ACKNOWLEDGMENTS

Because this document is a product of the efforts of many individuals, it is impossible to acknowledge each person who has contributed. Special recognition is given to Environmental Protection Agency employees in the Technical Development Section, National Air Data Branch, Monitoring and Data Analysis Division, for their efforts in the production of this work. Bylines identify the contributions of individual authors who revised specific sections and chapters.

PUBLICATIONS IN SERIES

Issuance	Release Date
Compilation of Air Pollutant Emission Factors (second edition)	4/73
Supplement No. 1	7/73
Section 4.3 Storage of Petroleum Products	
Section 4.4 Marketing and Transportation of Petroleum Products	
Supplement No. 2	9/73
Introduction	
Section 3.1.1 Average Emission Factors for Highway Vehicles	
Section 3.1.2 Light-Duty, Gasoline-Powered Vehicles	
Supplement No. 3	7/74
Introduction	
Section 1.4 Natural Gas Combustion	
Section 1.5 Liquified Petroleum Gas Consumption	
Section 1.6 Wood/Bark Waste Combustion in Boilers	
Section 2.5 Sewage Sludge Incineration	
Section 7.6 Lead Smelting	
Section 7.11 Secondary Lead Smelting	
Section 10.1 Chemical Wood Pulping	
Section 10.2 Pulpboard	
Section 10.3 Plywood Veneer and Layout Operations	
Supplement No. 4	1/75
Section 3.2.3 Inboard-Powered Vessels	
Section 3.2.5 Small, General Utility Engines	
Section 3.2.6 Agricultural Equipment	
Section 3.2.7 Heavy-Duty Construction Equipment	
Section 3.2.8 Snowmobiles	
Section 3.3.1 Stationary Gas Turbines for Electric Utility Power Plants	
Section 3.3.3 Gasoline and Diesel Industrial Engines	
Chapter 11 Miscellaneous Sources	
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Section 1.7 Lignite Combustion	
Section 3.1.1 Average Emission Factors for Highway Vehicles	
Section 3.1.2 Light-Duty, Gasoline-Powered Vehicles (Automobiles)	
Section 3.1.3 Light-Duty, Diesel-Powered Vehicles	
Section 3.1.4 Light-Duty, Gasoline-Powered Trucks and Heavy-Duty, Gasoline-Powered Vehicles	
Section 3.1.5 Heavy-Duty, Diesel-Powered Vehicles	
Section 5.6 Explosives	
Section 11.2 Fugitive Dust Sources	
Appendix C NEDS Source Classification Codes and Emission Factor Listing	
Appendix D Projected Emission Factors for Highway Vehicles	

	Issuance	Release Date
Supplement No. 6		4/76
Section 1.3	Fuel Oil Combustion	
Section 2.4	Open Burning	
Section 3.3-2	Heavy-Duty, Natural-Gas-Fired Pipeline Compressor Engines	
Section 6.1	Alfalfa Dehydrating	
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ABSTRACT

Emission data obtained from source tests, material balance studies, engineering estimates, etc., have been compiled for use by individuals and groups responsible for conducting air pollution emission inventories. Emission factors given in this document, the result of the expansion and continuation of earlier work, cover most of the common emission categories: fuel combustion by stationary and mobile sources; combustion of solid wastes; evaporation of fuels, solvents, and other volatile substances; various industrial processes; and miscellaneous sources. When no source-test data are available, these factors can be used to estimate the quantities of primary pollutants (particulates, CO, SO_2, NO_x, and hydrocarbons) being released from a source or source group.

Key words: fuel combustion, stationary sources, mobile sources, industrial processes, evaporative losses, emissions, emission data, emission inventories, primary pollutants, emission factors.

Table 1.1-2. EMISSION FACTORS FOR BITUMINOUS COAL COMBUSTION WITHOUT CONTROL EQUIPMENT
EMISSION FACTOR RATING: A

Furnace size, 10^6 Btu/hr heat input[a]	Particulates[b]		Sulfur oxides[c]		Carbon monoxide		Hydro-carbons[d]		Nitrogen oxides		Aldehydes	
	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned	lb/ton coal burned	kg/MT coal burned
Greater than 100[e] (Utility and large industrial boilers)												
Pulverized												
General	16A	8A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Wet bottom	13A[f]	6.5A	38S	19S	1	0.5	0.3	0.15	30	15	0.005	0.0025
Dry bottom	17A	8.5A	38S	19S	1	0.5	0.3	0.15	18	9	0.005	0.0025
Cyclone	2A	1A	38S	19S	1	0.5	0.3	0.15	55	27.5	0.005	0.0025
10 to 100[g] (large commercial and general industrial boilers)												
Spreader stoker[h]	13A[i]	6.5A	38S	19S	2	1	1	0.5	15	7.5	0.005	0.0025
Less than 10[j] (commercial and domestic furnaces)												
Underfeed stoker	2A	1A	38S	19S	10	5	3	1.5	6	3	0.005	0.0025
Hand-fired units	20	10	38S	19S	90	45	20	10	3	1.5	0.005	0.0025

[a] 1 Btu/hr = 0.252 kcal/hr.

[b] The letter A on all units other than hand-fired equipment indicates that the weight percentage of ash in the coal should be multiplied by the value given. *Example: If the factor is 16 and the ash content is 10 percent, the particulate emissions before the control equipment would be 10 times 16, or 160* pounds of particulate per ton of coal (10 times 8, or 80 kg of particulates per MT of coal).

[c] S equals the sulfur content (see footnote b above).

[d] Expressed as methane.

[e] References 1 and 3 through 7.

[f] Without fly-ash reinjection.

[g] References 1, 4, and 7 through 9.

[h] For all other stokers use 5A for particulate emission factor.

[i] Without fly-ash reinjection. With fly-ash reinjection use 20A. This value is not an emission factor but *represents loading reaching the control equipment.*[1]

[j] References 7, 9, and 10.

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1.3 FUEL OIL COMBUSTION *by Tom Lahre*

1.3.1 General[1,2]

Fuel oils are broadly classified into two major types: distillate and residual. Distillate oils (fuel oil grades 1 and 2) are used mainly in domestic and small commercial applications in which easy fuel burning is required. Distillates are more volatile and less viscous than residual oils as well as cleaner, having negligible ash and nitrogen contents and usually containing less than 0.3 percent sulfur (by weight). Residual oils (fuel oil grades 4, 5, and 6), on the other hand, are used mainly in utility, industrial, and large commercial applications in which sophisticated combustion equipment can be utilized. (Grade 4 oil is sometimes classified as a distillate; grade 6 is sometimes referred to as Bunker C.) Being more viscous and less volatile than distillate oils, the heavier residual oils (grades 5 and 6) must be heated for ease of handling and to facilitate proper atomization. Because residual oils are produced from the residue left over after the lighter fractions (gasoline, kerosene, and distillate oils) have been removed from the crude oil, they contain significant quantities of ash, nitrogen, and sulfur. Properties of typical fuel oils are given in Appendix A.

1.3.2 Emissions

Emissions from fuel oil combustion are dependent on the grade and composition of the fuel, the type and size of the boiler, the firing and loading practices used, and the level of equipment maintenance. Table 1.3-1 presents emission factors for fuel oil combustion in units without control equipment. Note that the emission factors for industrial and commercial boilers are divided into distillate and residual oil categories because the combustion of each produces significantly different emissions of particulates, SO_x, and NO_x. The reader is urged to consult the references cited for a detailed discussion of all of the parameters that affect emissions from oil combustion.

1.3.2.1 Particulates[3-6, 12, 13] – Particulate emissions are most dependent on the grade of fuel fired. The lighter distillate oils result in significantly lower particulate formation than do the heavier residual oils. Among residual oils, grades 4 and 5 usually result in less particulate than does the heavier grade 6.

In boilers firing grade 6, particulate emissions can be described, on the average, as a function of the sulfur content of the oil. As shown in Table 1.3-1 (footnote c), particulate emissions can be reduced considerably when low-sulfur grade 6 oil is fired. This is because low-sulfur grade 6, whether refined from naturally occurring low-sulfur crude oil or desulfurized by one of several processes currently in practice, exhibits substantially lower viscosity and reduced asphaltene, ash, and sulfur content – all of which result in better atomization and cleaner combustion.

Boiler load can also affect particulate emissions in units firing grade 6 oil. At low load conditions, particulate emissions may be lowered by 30 to 40 percent from utility boilers and by as much as 60 percent from small industrial and commercial units. No significant particulate reductions have been noted at low loads from boilers firing any of the lighter grades, however. At too low a load condition, proper combustion conditions cannot be maintained and particulate emissions may increase drastically. It should be noted, in this regard, that any condition that prevents proper boiler operation can result in excessive particulate formation.

1.3.2.2 Sulfur Oxides (SO_x)[1-5] – Total sulfur oxide emissions are almost entirely dependent on the sulfur content of the fuel and are not affected by boiler size, burner design, or grade of fuel being fired. On the average, more than 95 percent of the fuel sulfur is converted to SO_2, with about 1 to 3 percent further oxidized to SO_3. Sulfur trioxide readily reacts with water vapor (both in the air and in the flue gases) to form a sulfuric acid mist.

Table 1.3-1. EMISSION FACTORS FOR FUEL OIL COMBUSTION EMISSION FACTOR RATING: A

Pollutant	Type of boiler[a]							
	Power plant		Industrial and commercial				Domestic	
	Residual oil		Residual oil		Distillate oil		Distillate oil	
	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter	$lb/10^3$ gal	$kg/10^3$ liter
Particulate[b]	c	c	c	c	2	0.25	2.5	0.31
Sulfur dioxide[d]	157S	19S	157S	19S	142S	17S	142S	17S
Sulfur trioxide[d]	2S	0.25S	2S	0.25S	2S	0.25S	2S	0.25S
Carbon monoxide[e]	5	0.63	5	0.63	5	0.63	5	0.63
Hydrocarbons (total, as CH_4)[f]	1	0.12	1	0.12	1	0.12	1	0.12
Nitrogen oxides (total, as NO_2)[g]	105(50)[h,i]	12.6(6.25)[h,i]	60[j]	7.5[j]	22	2.8	18	2.3

[a]Boilers can be classified, roughly, according to their gross (higher) heat input rate, as shown below.

Power plant (utility) boilers: $>250 \times 10^6$ Btu/hr ($>63 \times 10^6$ kg-cal/hr)

Industrial boilers: $>15 \times 10^6$, but $<250 \times 10^6$ Btu/hr ($>3.7 \times 10^6$, but $<63 \times 10^6$ kg-cal/hr)

Commercial boilers: $>0.5 \times 10^6$, but $<15 \times 10^6$ Btu/hr ($>0.13 \times 10^6$, but $<3.7 \times 10^6$ kg-cal/hr)

Domestic (residential) boilers: $<0.5 \times 10^6$ Btu/hr ($<0.13 \times 10^6$ kg-cal/hr)

[b]Based on References 3 through 6. Particulate is defined in this section as that material collected by EPA Method 5 (front half catch)7.

[c]Particulate emission factors for residual oil combustion are best described, on the average, as a function of fuel oil grade and sulfur content, as shown below.

Grade 6 oil: $lb/10^3$ gal = 10 (S) + 3
[$kg/10^3$ liter = 1.25 (S) + 0.38]
Where: S is the percentage, by weight, of sulfur in the oil

Grade 5 oil: 10 $lb/10^3$ gal (1.25 $kg/10^3$ liter)

Grade 4 oil: 7 $lb/10^3$ gal (0.88 $kg/10^3$ liter)

[d]Based on References 1 through 5. S is the percentage, by weight, of sulfur in the oil.

[e]Based on References 3 through 5 and 8 through 10. Carbon monoxide emissions may increase by a factor of 10 to 100 if a unit is improperly operated or not well maintained.

[f]Based on References 1, 3 through 5, and 10. Hydrocarbon emissions are generally negligible unless unit is improperly operated or not well maintained, in which case emissions may increase by several orders of magnitude.

[g]Based on References 1 through 5 and 8 through 11.

[h]Use 50 $lb/10^3$ gal (6.25 $kg/10^3$ liter) for tangentially fired boilers and 105 $lb/10^3$ gal (12.6 $kg/10^3$ liter) for all others, at full load, and normal (>15 percent) excess air. At reduced loads, NO_x emissions are reduced by 0.5 to 1 percent, on the average, for every percentage reduction in boiler load.

[i]Several combustion modifications can be employed for NO_x reduction: (1) limited excess air firing can reduce NO_x emissions by 5 to 30 percent, (2) staged combustion can reduce NO_x emissions by 20 to 45 percent, and (3) flue gas recirculation can reduce NO_x emissions by 10 to 45 percent. Combinations of the modifications have been employed to reduce NO_x emissions by as much as 60 percent in certain boilers. See section 1.4 for a discussion of these NO_x-reducing techniques.

[j]Nitrogen oxides emissions from residual oil combustion in industrial and commercial boilers are strongly dependent on the fuel nitrogen content and can be estimated more accurately by the following empirical relationship:

$lb\ NO_2/10^3\ gal = 22 + 400\ (N)^2$

$[kg\ NO_2/10^3\ liters = 2.75 + 50\ (N)^2]$

Where: N is the nitrogen content, by weight, in the oil.

1.3.2.3 Nitrogen Oxides (NO_x)[1-6, 8-11, 14] – Two mechanisms form nitrogen oxides: oxidation of fuel-bound nitrogen and thermal fixation of the nitrogen present in combustion air. Fuel NO_x are primarily a function of the nitrogen content of the fuel and the available oxygen (on the average, about 45 percent of the fuel nitrogen is converted to NO_x, but this may vary from 20 to 70 percent). Thermal NO_x, on the other hand, are largely a function of peak flame temperature and available oxygen – factors which are dependent on boiler size, firing configuration, and operating practices.

Fuel nitrogen conversion is the more important NO_x-forming mechanism in boilers firing residual oil. Except in certain large units having unusually high peak flame temperatures, or in units firing a low-nitrogen residual oil, fuel NO_x will generally account for over 50 percent of the total NO_x generated. Thermal fixation, on the other hand, is the predominant NO_x-forming mechanism in units firing distillate oils, primarily because of the negligible nitrogen content in these lighter oils. Because distillate-oil-fired boilers usually have low heat release rates, however, the quantity of thermal NO_x formed in them is less than in larger units.

A number of variables influence how much NO_x is formed by these two mechanisms. One important variable is firing configuration. Nitrogen oxides emissions from tangentially (corner) fired boilers are, on the average, only half those of horizontally opposed units. Also important are the firing practices employed during boiler operation. The use of limited excess air firing, flue gas recirculation, staged combustion, or some combination thereof, may result in NO_x reductions ranging from 5 to 60 percent. (See section 1.4 for a discussion of these techniques.) Load reduction can likewise decrease NO_x production. Nitrogen oxides emissions may be reduced from 0.5 to 1 percent for each percentage reduction in load from full load operation. It should be noted that most of these variables, with the exception of excess air, are applicable only in large oil-fired boilers. Limited excess air firing is possible in many small boilers, but the resulting NO_x reductions are not nearly as significant.

1.3.2.4 Other Pollutants [1, 3-5, 8-10, 14] – As a rule, only minor amounts of hydrocarbons and carbon monoxide will be produced during fuel oil combustion. If a unit is operated improperly or not maintained, however, the resulting concentrations of these pollutants may increase by several orders of magnitude. This is most likely to be the case with small, often unattended units.

1.3.3 Controls

Various control devices and/or techniques may be employed on oil-fired boilers depending on the type of boiler and the pollutant being controlled. All such controls may be classified into three categories: boiler modification, fuel substitution, and flue gas cleaning.

1.3.3.1 Boiler Modification[1-4, 8, 9, 13, 14] – Boiler modification includes any physical change in the boiler apparatus itself or in the operation thereof. Maintenance of the burner system, for example, is important to assure proper atomization and subsequent minimization of any unburned combustibles. Periodic tuning is important in small units to maximize operating efficiency and minimize pollutant emissions, particularly smoke and CO. Combustion modifications such as limited excess air firing, flue gas recirculation, staged combustion, and reduced load operation all result in lowered NO_x emissions in large facilities. (See Table 1.3-1 for specific reductions possible through these combustion modifications.)

1.3.3.2 Fuel Substitution[3-5, 12] – Fuel substitution, that is, the firing of "cleaner" fuel oils, can substantially reduce emissions of a number of pollutants. Lower sulfur oils, for instance, will reduce SO_x emissions in all boilers regardless of size or type of unit or grade of oil fired. Particulates will generally be reduced when a better grade of oil is fired. Nitrogen oxide emissions will be reduced by switching to either a distillate oil or a residual oil containing less nitrogen. The practice of fuel substitution, however, may be limited by the ability of a given operation to fire a better grade of oil as well as the cost and availability thereof.

1.3.3.3 Flue Gas Cleaning[6, 15-21] – Flue gas cleaning equipment is generally only employed on large oil-fired boilers. Mechanical collectors, a prevalent type of control device, are primarily useful in controlling particulates generated during soot blowing, during upset conditions, or when a very dirty, heavy oil is fired. During these situations, high efficiency cyclonic collectors can effect up to 85 percent control of particulate. Under normal firing conditions, however, or when a clean oil is combusted, cyclonic collectors will not be nearly as effective.

Electrostatic precipitators are commonly found in power plants that at one time fired coal. Precipitators that were designed for coal flyash provide only 40 to 60 percent control of oil-fired particulate. Collection efficiencies of up to 90 percent, however, have been reported for new or rebuilt devices that were specifically designed for oil-firing units.

Scrubbing systems have been installed on oil-fired boilers, especially of late, to control both sulfur oxides and particulate. These systems can achieve SO_2 removal efficiencies of up to 90 to 95 percent and provide particulate control efficiencies on the order of 50 to 60 percent. The reader should consult References 20 and 21 for details on the numerous types of flue gas desulfurization systems currently available or under development.

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2.4.1 General[1]

Open burning can be done in open drums or baskets, in fields, and in large open dumps or pits. Materials commonly disposed of in this manner are municipal waste, auto body components, landscape refuse, agricultural field refuse, wood refuse, and bulky industrial refuse.

2.4.2 Emissions[1-17]

Ground-level open burning is affected by many variables including wind, ambient temperature, composition and moisture content of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase the emission of particulates, carbon monoxide, and hydrocarbons and suppress the emission of nitrogen oxides. Sulfur oxide emissions are a direct function of the sulfur content of the refuse. Emission factors are presented in Table 2.4-1 for the open burning of municipal refuse and automobile components.

Table 2.4-1. EMISSION FACTORS FOR OPEN BURNING OF NONAGRICULTURAL MATERIAL
EMISSION FACTOR RATING: B

	Particulates	Sulfur oxides	Carbon monoxide	Hydrocarbons (CH_4)	Nitrogen oxides
Municipal refuse[a]					
lb/ton	16	1	85	30	6
kg/MT	8	0.5	42	15	3
Automobile components[b,c]					
lb/ton	100	Neg.	125	30	4
kg/MT	50	Neg.	62	15	2

[a]References 2 through 6.
[b]Upholstery, belts, hoses, and tires burned in common.
[c]Reference 2.

Emissions from agricultural refuse burning are dependent mainly on the moisture content of the refuse and, in the case of field crops, on whether the refuse is burned in a headfire or a backfire. (Headfires are started at the upwind side of a field and allowed to progress in the direction of the wind, whereas backfires are started at the downwind edge and forced to progress in a direction opposing the wind.) Other variables such as fuel loading (how much refuse material is burned per unit of land area) and how the refuse is arranged (that is, in piles, rows, or spread out) are also important in certain instances.

Emission factors for open agricultural burning are presented in Table 2.4-2 as a function of refuse type and also, in certain instances, as a function of burning techniques and/or moisture content when these variables are known to significantly affect emissions.

Table 2.4-2 also presents typical fuel loading values associated with each type of refuse. These values can be used, along with the corresponding emission factors, to estimate emissions from certain categories of agricultural burning when the specific fuel loadings for a given area are not known.

For more detailed information on this subject, the reader should consult the references cited at the end of this section. The background material for this section was prepared for EPA by Pacific Environmental Services, Inc.

Table 2.4-2. EMISSION FACTORS AND FUEL LOADING FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS[a]
EMISSION FACTOR RATING: B

Refuse category	Emission factors						Fuel loading factors (waste production)	
	Particulate[b]		Carbon monoxide		Hydrocarbons (as C_6H_{14})			
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	ton/acre	MT/hectare
Field crops[c]								
Unspecified	21	11	117	58	23	12	2.0	4.5
Burning technique not significant[d]								
Asparagus[e]	40	20	150	75	85	42	1.5	3.4
Barley	22	11	157	78	19	10	1.7	3.8
Corn	14	7	108	54	16	8	4.2	9.4
Cotton	8	4	176	88	6	3	1.7	3.8
Grasses	16	8	101	50	19	10		
Pineapple[f]	8	4	112	56	8	4		
Rice[g]	9	4	83	41	10	5	3.0	6.7
Safflower	18	9	144	72	26	13	1.3	2.9
Sorghum	18	9	77	38	9	4	2.9	6.5
Sugar cane[h]	7	4	71	35	10	5	11.0	24.0
Headfire burning[i]								
Alfalfa	45	23	106	53	36	18	0.8	1.8
Bean (red)	43	22	186	93	46	23	2.5	5.6
Hay (wild)	32	16	139	70	22	11	1.0	2.2
Oats	44	22	137	68	33	16	1.6	3.6
Pea	31	16	147	74	38	19	2.5	5.6
Wheat	22	11	128	64	17	9	1.9	4.3
Backfire burning[j]								
Alfalfa	29	14	119	60	37	18	0.8	1.8
Bean (red), pea	14	7	148	72	25	12	2.5	5.6
Hay (wild)	17	8	150	75	17	8	1.0	2.2
Oats	21	11	136	68	18	9	1.6	3.6
Wheat	13	6	108	54	11	6	1.9	4.3
Vine crops	5	3	51	26	7	4	2.5	5.6
Weeds								
Unspecified	15	8	85	42	12	6	3.2	7.2
Russian thistle (tumbleweed)	22	11	309	154	2	1	0.1	0.2
Tules (wild reeds)	5	3	34	17	27	14		
Orchard crops[c,k,l]								
Unspecified	6	3	52	26	10	5	1.6	3.6
Almond	6	3	46	23	8	4	1.6	3.6
Apple	4	2	42	21	4	2	2.3	5.2
Apricot	6	3	49	24	8	4	1.8	4.0
Avocado	21	10	116	58	32	16	1.5	3.4
Cherry	8	4	44	22	10	5	1.0	2.2
Citrus (orange, lemon)	6	3	81	40	12	6	1.0	2.2
Date palm	10	5	56	28	7	4	1.0	2.2
Fig	7	4	57	28	10	5	2.2	4.9

Table 2.4-2 (continued). EMISSION FACTORS AND FUEL LOADING FACTORS FOR OPEN BURNING OF AGRICULTURAL MATERIALS[a]
EMISSION FACTOR RATING: B

Refuse category	Emission factors						Fuel loading factors (waste production)	
	Particulate[b]		Carbon monoxide		Hydrocarbons (as C_6H_{14})			
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	ton/acre	MT/hectare
Orchard crops[c,k,l] (continued)								
Nectarine	4	2	33	16	4	2	2.0	4.5
Olive	12	6	114	57	18	9	1.2	2.7
Peach	6	3	42	21	5	2	2.5	5.6
Pear	9	4	57	28	9	4	2.6	5.8
Prune	3	2	42	21	3	2	1.2	2.7
Walnut	6	3	47	24	8	4	1.2	2.7
Forest residues								
Unspecified[m]	17	8	140	70	24	12	70	157
Hemlock, Douglas fir, cedar[n]	4	2	90	45	5	2		
Ponderosa pine[o]	12	6	195	98	14	7		

[a]Factors expressed as weight of pollutant emitted per weight of refuse material burned.
[b]Particulate matter from most agricultural refuse burning has been found to be in the submicrometer size range.[12]
[c]References 12 and 13 for emission factors; Reference 14 for fuel loading factors.
[d]For these refuse materials, no significant difference exists between emissions resulting from headfiring or backfiring.
[e]These factors represent emissions under typical high moisture conditions. If ferns are dried to less than 15 percent moisture, particulate emissions will be reduced by 30 percent, CO emission by 23 percent, and HC by 74 percent.
[f]When pineapple is allowed to dry to less than 20 percent moisture, as it usually is, the firing technique is not important. When headfired above 20 percent moisture, particulate emission will increase to 23 lb/ton (11.5 kg/MT) and HC will increase to 12 lb/ton (6 kg/MT). See Reference 11.
[g]This factor is for dry (<15 percent moisture) rice straw. If rice straw is burned at higher moisture levels, particulate emission will increase to 29 lb/ton (14.5 kg/MT), CO emission to 161 lb/ton (80.5 kg/MT), and HC emission to 21 lb/ton (10.5 kg/MT).
[h]See Section 6.12 for discussion of sugar cane burning.
[i]See accompanying text for definition of headfiring.
[j]See accompanying text for definition of backfiring. This category, for emission estimation purposes, includes another technique used occasionally for limiting emissions, called into-the-wind striplighting, which involves lighting fields in strips into the wind at 100-200 m (300-600 ft) intervals.
[k]Orchard prunings are usually burned in piles. No significant difference in emission results from burning a "cold pile" as opposed to using a roll-on technique, where prunings are bulldozed onto a bed of embers from a preceding fire.
[l]If orchard removal is the purpose of a burn, 30 ton/acre (66 MT/hectare) of waste will be produced.
[m]Reference 10. Nitrogen oxide emissions estimated at 4 lb/ton (2 kg/MT).
[n]Reference 15.
[o]Reference 16.

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3.3.2 Heavy-Duty, Natural-Gas-Fired Pipeline Compressor Engines

by Susan Sercer
Alan Burgess
Tom Lahre

3.3.2.1 General[1] – Engines in the natural gas industry are used primarily to power compressors used for pipeline transportation, field gathering (collecting gas from wells), underground storage, and gas processing plant applications. Pipeline engines are concentrated in the major gas producing states (such as those along the Gulf Coast) and along the major gas pipelines. Both reciprocating engines and gas turbines are utilized, but the trend has been toward use of large gas turbines. Gas turbines emit considerably fewer pollutants than do reciprocating engines; however, reciprocating engines are generally more efficient in their use of fuel.

3.3.2.2 Emissions and Controls[1,2] – The primary pollutant of concern is NO_x, which readily forms in the high temperature, pressure, and excess air environment found in natural-gas-fired compressor engines. Lesser amounts of carbon monoxide and hydrocarbons are emitted, although for each unit of natural gas burned, compressor engines (particularly reciprocating engines) emit significantly more of these pollutants than do external combustion boilers. Sulfur oxides emissions are proportional to the sulfur content of the fuel and will usually be quite low because of the negligible sulfur content of most pipeline gas.

The major variables affecting NO_x emissions from compressor engines include the air fuel ratio, engine load (defined as the ratio of the operating horsepower divided by the rated horsepower), intake (manifold) air temperature, and absolute humidity. In general, NO_x emissions increase with increasing load and intake air temperature and decrease with increasing absolute humidity and air fuel ratio. (The latter already being, in most compressor engines, on the "lean" side of that air fuel ratio at which maximum NO_x formation occurs.) Quantitative estimates of the effects of these variables are presented in Reference 2.

Because NO_x is the primary pollutant of significance emitted from pipeline compressor engines, control measures to date have been directed mainly at limiting NO_x emissions. For gas turbines, the most effective method of controlling NO_x emissions is the injection of water into the combustion chamber. Nitrogen oxides reductions as high as 80 percent can be achieved by this method. Moreover, water injection results in only nominal reductions in overall turbine efficiency. Steam injection can also be employed, but the resulting NO_x reductions may not be as great as with water injection, and it has the added disadvantage that a supply of steam must be readily available. Exhaust gas recirculation, wherein a portion of the exhaust gases is recirculated back into the intake manifold, may result in NO_x reductions of up to 50 percent. This technique, however, may not be practical in many cases because the recirculated gases must be cooled to prevent engine malfunction. Other combustion modifications, designed to reduce the temperature and/or residence time of the combustion gases, can also be effective in reducing NO_x emissions by 10 to 40 percent in specific gas turbine units.

For reciprocating gas-fired engines, the most effective NO_x control measures are those that change the air-fuel ratio. Thus, changes in engine torque, speed, intake air temperature, etc., that in turn increase the air-fuel ratio, may all result in lower NO_x emissions. Exhaust gas recirculation may also be effective in lowering NO_x emissions although, as with turbines, there are practical limits because of the large quantities of exhaust gas that must be cooled. Available data suggest that other NO_x control measures, including water and steam injection, have only limited application to reciprocating gas-fired engines.

Emission factors for natural-gas-fired pipeline compressor engines are presented in Table 3.3.2-1.

Table 3.3.2-1. EMISSION FACTORS FOR HEAVY-DUTY, NATURAL-GAS-FIRED PIPELINE COMPRESSOR ENGINES[a]

EMISSION FACTOR RATING: A

	Nitrogen oxides (as NO_2)[b]	Carbon monoxide	Hydrocarbons (as C)[c]	Sulfur dioxide[d]	Particulate[e]
Reciprocating engines					
lb/10^3 hp-hr	24	3.1	9.7	0.004	NA
g/hp-hr	11	1.4	4.4	0.002	NA
g/kW-hr	15	1.9	5.9	0.003	NA
lb/10^6 scf[f]	3,400	430	1,400	0.6	NA
kg/10^6 Nm^3[f]	55,400	7,020	21,800	9.2	NA
Gas turbines					
lb/10^3 hp-hr	2.9	1.1	0.2	0.004	NA
g/hp-hr	1.3	0.5	0.1	0.002	NA
g/kW-hr	1.7	0.7	0.1	0.003	NA
lb/10^6 scf[g]	300	120	23	0.6	NA
kg/10^6 Nm^3[g]	4,700	1,940	280	9.2	NA

[a]All factors based on References 2 and 3.

[b]These factors are for compressor engines operated at rated load. In general, NO_x emissions will increase with increasing load and intake (manifold) air temperature and decrease with increasing air-fuel ratios (excess air rates) and absolute humidity. Quantitative estimates of the effects of these variables are presented in Reference 2.

[c]These factors represent total hydrocarbons. Nonmethane hydrocarbons are estimated to make up to 5 to 10 percent of these totals, on the average.

[d]Based on an assumed sulfur content of pipeline gas of 2000 gr/10^6 scf (4600 g/Nm^3). If pipeline quality natural gas is not fired, a material balance should be performed to determine SO_2 emissions based on the actual sulfur content.

[e]Not available from existing data.

[f]*These factors are calculated from the above factors for reciprocating engines assuming a heating value of 1050 Btu/scf* (9350 kcal/Nm^3) for natural gas and an average fuel consumption of 7500 Btu/hp-hr (2530 kcal/kW-hr).

[g]These factors are calculated from the above factors for gas turbines assuming a heating value of 1,050 Btu/scf (9,350 kcal/Nm^3) of natural gas and an average fuel consumption of 10,000 Btu/hp-hr (3,380 kcal/kW-hr).

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For example, a technique used with some underground gasoline storage tanks consists of an arrangement by which vapors are recycled to the tank trucks during filling operations through the annular space of a specially designed "interlock valve" and into a side arm that is connected to the return manifold in the dome cap of the truck (see Figure 4.4-2). The control efficiency of this method ranges from 93 to 100 percent when compared with uncontrolled, splash-fill loading (see Table 4.4-1).

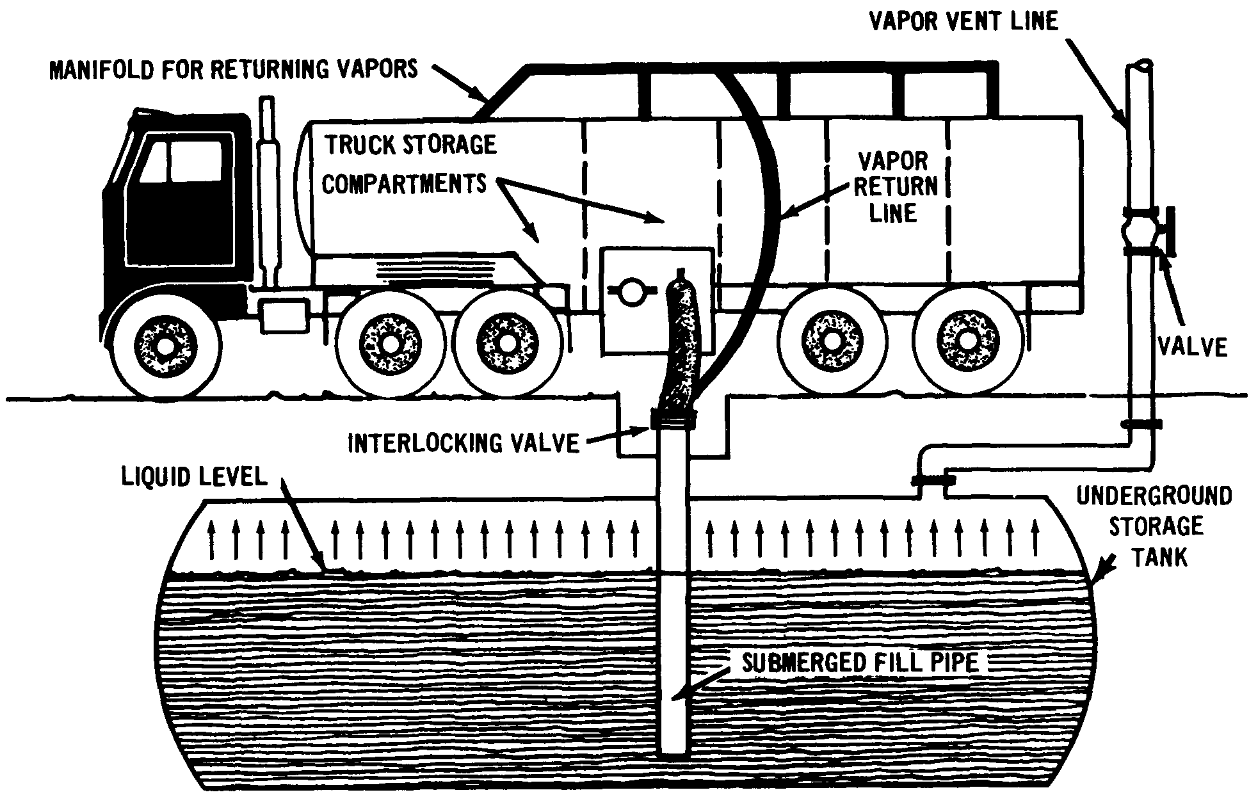

Figure 4.4-2. Underground storage tank vapor-recovery system[1].

Table 4.4-1. ORGANIC COMPOUND EVAPORATIVE EMISSION FACTORS FOR PETROLEUM TRANSPORTATION AND MARKETING SOURCES[a]
EMISSION FACTOR RATING: A

Emission source	Product				
	Gasoline	Crude oil	Naphtha jet fuel (JP-4)	Kerosene	Distillate oil
Tank cars/trucks[b]					
Splash loading					
lb/10^3 gal transferred	12.4	10.6	1.8	0.88	0.93
kg/10^3 liter transferred	1.5	1.3	0.22	0.11	0.11
Submerged loading					
lb/10^3 gal transferred	4.1	4.0	0.91	0.45	0.48
kg/10^3 liter transferred	0.49	0.48	0.11	0.054	0.058
Unloading					
lb/10^3 gal transferred	2.1	2.0	0.45	0.23	0.24
kg/10^3 liter transferred	0.25	0.24	0.054	0.028	0.029
Marine vessels[b]					
Loading					
lb/10^3 gal transferred	2.9	2.6	0.60	0.27	0.29
kg/10^3 liter transferred	0.35	0.31	0.072	0.032	0.035
Unloading					
lb/10^3 gal transferred	2.5	2.3	0.52	0.24	0.25
kg/10^3 liter transferred	0.30	0.28	0.062	0.029	0.030
Transit					
lb/wk-10^3 gal load	3.6	3.2	0.74	0.34	0.36
kg/wk-10^3 liter load	0.43	0.38	0.089	0.041	0.043
Underground gasoline storage tanks[c]					
Splash loading					
lb/10^3 gal transferred	11.5	NU[d]	NU	NU	NU
kg/10^3 liter transferred	1.4	NU	NU	NU	NU
Uncontrolled submerged loading					
lb/10^3 gal transferred	7.3	NU	NU	NU	NU
kg/10^3 liter transferred	0.84	NU	NU	NU	NU
Submerged loading with open vapor return system					
lb/10^3 gal transferred	0.80	NU	NU	NU	NU
kg/10^3 liter transferred	0.097	NU	NU	NU	NU
Submerged loading with closed vapor return system					
lb/10^3 gal transferred	Neg	NU	NU	NU	NU
kg/10^3 liter transferred	Neg	NU	NU	NU	NU

6. FOOD AND AGRICULTURAL INDUSTRY

Before food and agricultural products are used by the consumer they undergo a number of processing steps, such as refinement, preservation, and product improvement, as well as storage and handling, packaging, and shipping. This section deals with the processing of food and agricultural products and the intermediate steps that present air pollution problems. Emission factors are presented for industries where data were available. The primary pollutant emitted from these processes is particulate matter.

6.1 ALFALFA DEHYDRATING

by Tom Lahre

6.1.1 General[1-3]

Dehydrated alfalfa is a meal product resulting from the rapid drying of alfalfa by artifical means at temperatures above 212°F (100°C). Alfalfa meal is used 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.

A schematic of a generalized alfalfa dehydrator plant is given in Figure 6.1-1. Standing alfalfa is mowed and chopped in the field and transported by truck to a dehydrating plant, which is usually located within 10 miles of the field. 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 60 to 80 percent (by weight) to about 8 to 16 percent. Typical combustion gas temperatures within the oil- or gas-fired drums range from 1800 to 2000°F (980 to 1092°C) at the inlet to 250 to 300°F (120 to 150°C) 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. 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 removal is more commonly effected in shaker screens following or ahead of 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; however, in some instances, the pellets may be ground in a hammermill and shipped in meal form. When the finished pellets or ground pellets are pneumatically transferred to storage or loadout, additional cyclones may be employed for product airstream separation at these locations.

6.1.2 Emissions and Controls[1-3]

Particulate matter is the primary pollutant of concern from alfalfa dehydrating plants although some odors arise from the organic volatiles driven off during drying. Although the major source is the primary cooling cyclone, lesser sources include the downstream cyclone separators and the bagging and loading operations.

Emission factors for the various cyclone separators utilized in alfalfa dehydrating plants are given in Table 6.1-1. Note that, although these sources are common to many plants, there will be considerable variation from the generalized flow diagram in Figure 6.1-1 depending on the desired nature of the product, the physical layout of the plant, and the modifications made for air pollution control. Common variations include ducting the exhaust gas stream from one or more of the downstream cyclones back through the primary cyclone and ducting a portion of the primary cyclone exhaust back into the furnace. Another modification involves ducting a part of the meal collector cyclone exhaust back into the hammermill, with the remainder ducted to the primary cyclone or discharged directly to the atmosphere. Also, additional cyclones may be employed if the pellets are pneumatically rather than mechanically conveyed from the pellet mill to the cooler or if the finished pellets or ground pellets are pneumatically conveyed to storage or loadout.

Table 6.1-1. PARTICULATE EMISSION FACTORS FOR ALFALFA DEHYDRATING PLANTS
EMISSION FACTOR RATING: PRIMARY CYCLONES: A
ALL OTHER SOURCES: C

Sources[a]	Emissions	
	lb/ton of product[b]	kg/MT of product[b]
Primary cyclone	10 [c]	5 [c]
Meal collector cyclone[d]	2.6	1.3
Pellet collector cyclone[e]	Not available	Not available
Pellet cooler cyclone[f]	3	1.5
Pellet regrind cyclone[g]	8	4
Storage bin cyclone[h]	Neg.	Neg.

[a]The cyclones used for product/airstream separation are the air pollution sources in alfalfa dehydrating plants. All factors are based on References 1 and 2.

[b]Product consists of meal or pellets. These factors can be applied to the quantity of incoming wet chops by dividing by a factor of four.

[c]This average factor may be used even when other cyclone exhaust streams are ducted back into the primary cyclone. Emissions from primary cyclones may range from 3 to 35 lb/ton (1.5 to 17.5 kg/MT) of product and are more a function of the operating procedures and process modifications made for air pollution control than whether other cyclone exhausts are ducted back through the primary cyclone. Use 3 to 15 lb/ton (1.5 to 7.5 kg/MT) for plants employing good operating procedures and process modifications for air pollution control. Use higher values for older, unmodified, or less well run plants.

[d]This cyclone is also called the air meal separator or hammermill cyclone. When the meal collector exhaust is ducted back to the primary cyclone and/or the hammermill, this cyclone is no longer a source.

[e]This cyclone will only be present if the pellets are pneumatically transferred from the pellet mill to the pellet cooler.

[f]This cyclone is also called the pellet meal air separator or pellet mill cyclone. When the pellet cooler cyclone exhaust is ducted back into the primary cyclone, it is no longer a source.

[g]This cyclone is also called the pellet regrind air separator. Regrind operations are more commonly found at terminal storage facilities than at dehydrating plants.

[h]Small cyclone collectors may be used to collect the finished pellets when they are pneumatically transferred to storage.

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.

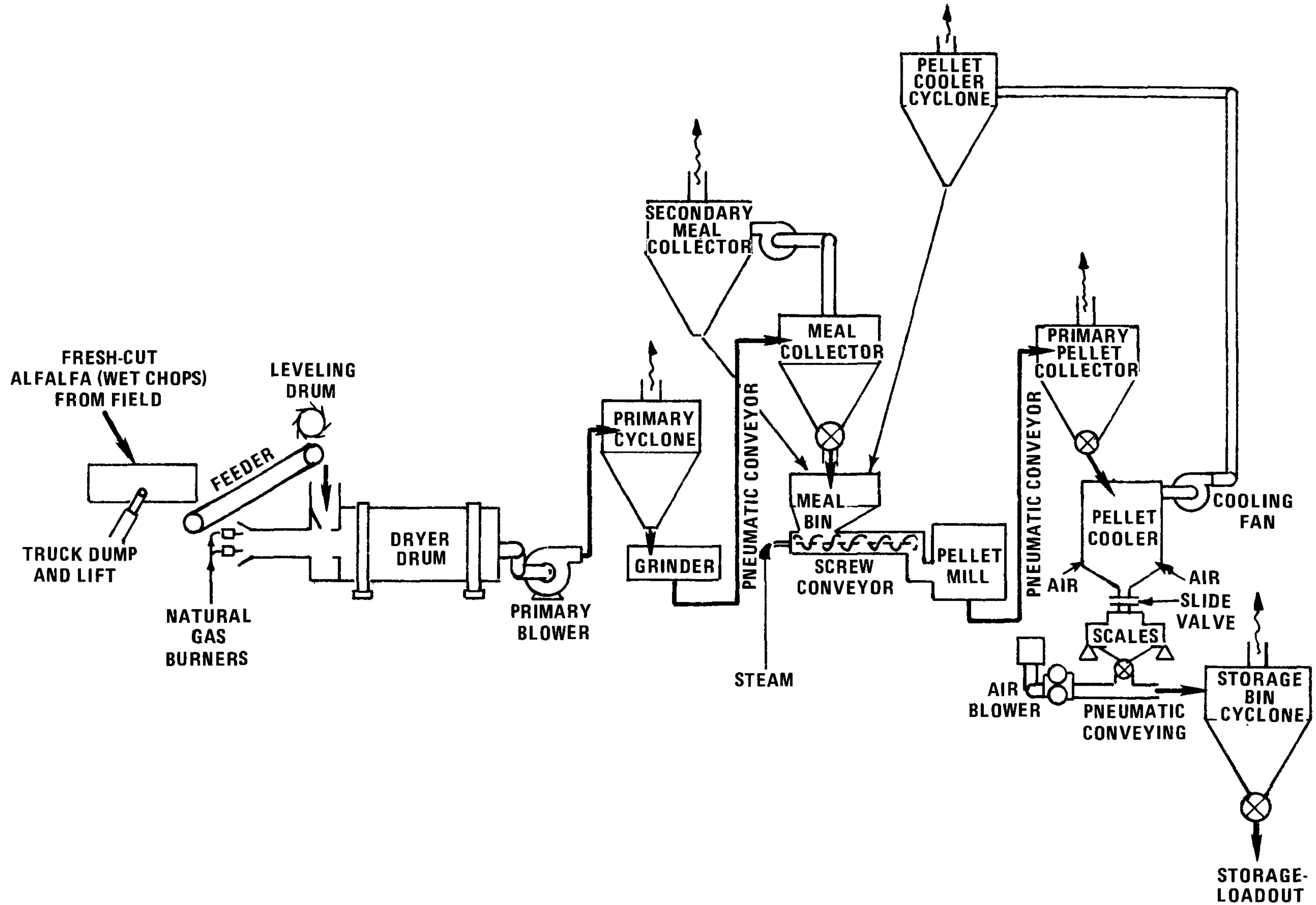

Figure 6.1-1. Generalized flow diagram for alfalfa dehydration plant.

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. 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.

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. Some measure of secondary control can also be effected on these cyclones by ducting their exhaust streams back into the primary cyclone. 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 furnace for incineration. 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.

References for Section 6.1

1. Source information supplied by Ken Smith of the American Dehydrators Association, Mission, Kan. December 1975.

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3. Smith, K.D. Particulate Emissions from Alfalfa Dehydrating Plants - Control Costs and Effectiveness. Final Report. American Dehydrators Association. Mission, Kan. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. Grant No. R801446. Publication No. 650/2-74-007. January 1974.

6.12 SUGAR CANE PROCESSING

revised by Tom Lahre

6.12.1 General [1-3]

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 one of two 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.

6.12.2 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 2.4-2. Emission factors for bagasse firing in boilers will be included in Chapter 1 in a future supplement.

References for Section 6.12

1. Sugar Cane. In: Kirk-Othmer Encyclopedia of Chemical Technology, Vol. IX. New York, John Wiley and Sons, Inc. 1964.

2. Darley, E. F. Air Pollution Emissions from Burning Sugar Cane and Pineapple from Hawaii. In: Air Pollution from Forest and Agricultural Burning. Statewide Air Pollution Research Center, University of California, Riverside, Calif. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Grant No. R800711. August 1974.

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more olefins (noncyclic unsaturated hydrocarbons with C=C double bonds), and alkylation unites an olefin and an iso-paraffin (noncyclic branched-chain hydrocarbon saturated with hydrogen). *Isomerization is the process for* altering the arrangement of atoms in a molecule without adding or removing anything from the original material, and is usually used in the oil industry to form branched-chain hydrocarbons. A number of catalysts such as phosphoric acid, sulfuric acid, platinum, aluminum chloride, and hydrofluoric acid are used to promote the combination or rearrangement of these light hydrocarbons.

9.1.3.5 Emissions–These three processes, including regeneration of any necessary catalysts, form essentially closed systems and have no unique, major source of atmospheric emissions. However, the highly volatile hydrocarbons handled, coupled with the high process pressures required, make valve stems and pump shafts difficult to seal, and a greater emission rate from these sources can generally be expected in these process areas than would be the average throughout the refinery. The best method for controlling these emissions is the effective maintenance, repair, and replacement of pump seals, valve caulking, and pipe-joint sealer.

9.1.4 Treating

"Hydrogen," "chemical," and "physical" treating are used in the refinery process to remove undesirable impurities such as sulfur, nitrogen, and oxygen to improve product quality.

9.1.4.1 Hydrogen Treating[1]–In this procedure hydrogen is reacted with impurities in compounds to produce removable hydrogen sulfide, ammonia, and water. In addition, the process converts diolefins (gum-forming hydrocarbons with the empirical formula R=C=R) into stable compounds while minimizing saturation of desirable aromatics.

Hydrogenation units are nearly all the fixed-bed type with catalyst replacement or regeneration (by combustion) done intermittently, the frequency of which is dependent upon operating conditions and the product being treated. The hydrogen sulfide produced is removed from the hydrogen stream via extraction and converted to elemental sulfur or sulfuric acid or, when present in small quantities, burned to SO_2 in a flare or boiler firebox.

9.1.4.2 Chemical Treating[1]–Chemical treating is generally classified into four groups: (1) acid treatment, (2) sweetening, (3) solvent extraction, and (4) additives. Acid treatment involves contacting hydrocarbons with sulfuric acid to partially remove sulfur and nitrogen compounds, to precipitate asphaltic or gum-like materials, and to improve color and odor. Spent acid sludges that result are usually converted to ammonium sulfate or sulfuric acid.

Sweetening processes oxidize mercaptans (formula: R-S-H) to disulfide (formula: R-S-S-R′) without actual sulfur removal. In some processes, air and steam are used for agitation in mixing tanks and to reactivate chemical solutions.

Solvent extraction utilizes solvents that have affinities for the undesirable compounds and that can easily be removed from the product stream. Specifically, mercaptan compounds are usually extracted using a strong caustic solution; hydrogen sulfide is removed by a number of commercial processes.

Finally, additives or inhibitors are primarily materials added in small amounts to oxidize mercaptans to disulfide and to retard gum formation.

9.1.4.3 Physical Treating[1]—Some of the many physical methods used to remove impurities include electrical coalescence, filtration, absorption, and air blowing. Specific applications of physical methods are desalting crude oil, removing wax, decolorizing lube oils, and brightening diesel oil.

9.1.4.4 Emissions – Emissions from treating operations consist of SO_2, hydrocarbons, and visible plumes. Emission levels depend on the methods used in handling spent acid and acid sludges, as well as the means employed for recovery or disposal of hydrogen sulfide. Other potential sources of these emissions in treating include catalyst regeneration, air agitation in mixing tanks, and other air blowing operations. Trace amounts of malodorous substances may escape from numerous sources including settling tank vents, purge tanks, waste treatment units, waste-water drains, valves, and pump seals.

Control methods used include: covers for waste water separators; vapor recovery systems for settling and surge tanks; improved maintenance for pumps, valves, etc; and sulfur recovery plants.

9.1.5 Blending[1]

The final major operation in petroleum refining consists of blending the products in various proportions to meet certain specifications, such as vapor pressure, specific gravity, sulfur content, viscosity, octane number, initial boiling point, and pour point.

9.1.5.1 Emissions – Emissions associated with this operation are hydrocarbons that leak from storage vessels, valves, and pumps. Vapor recovery systems and specially built tanks minimize storage emissions; good housekeeping precludes pump and valve leakage.

9.1.6 Miscellaneous Operations[1]

In addition to the four refinery operations described above, there are many process operations connected with all four. These involve the use of cooling towers, blow-down systems, process heaters and boilers, compressors, and process drains. The emissions and controls associated with these operations are listed in Table 9.1-1.

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1. Atmospheric Emissions from Petroleum Refineries: A Guide for Measurement and Control. U.S. DHEW, Public Health Service. Washington, D.C. PHS Publication Number 763. 1960.

2. Impurities in Petroleum. In: Petreco Manual. Long Beach, Petrolite Corp. 1958. p.1.

3. Jones, Ben G. Refinery Improves Particulate Control. The Oil and Gas Journal. *69*(26):60-62. June 28, 1971.

4. Private communications with personnel in the Emission Testing Branch, Applied Technology Division, Environmental Protection Agency, Research Triangle Park, N.C., regarding source testing at a petroleum refinery preparatory to setting new source standards. June-August 1972.

5. Control Techniques for Sulfur Oxide in Air Pollutants. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C. Publication Number AP-52. January 1969.

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9.2 NATURAL GAS PROCESSING

by Harry Butcher and Tom Lahre

9.2.1 General[1]

Natural gas from high-pressure wells is usually passed through field separators to remove hydrocarbon condensate and water at the well. Natural gasoline, butane, and propane are usually present in the gas, and gas processing plants are required for the recovery of these liquefiable constituents (see Figure 9.2-1). Natural gas is considered "sour" if hydrogen sulfide is present in amounts greater than 0.25 grain per 100 standard cubic feet. The hydrogen sulfide (H_2S) must be removed (called "sweetening" the gas) before the gas can be utilized. If H_2S is present, the gas is usually sweetened by absorption of the H_2S in an amine solution. Amine processes are used for over 95 percent of all gas sweetening in the United States. Processes such as carbonate processes, solid bed absorbents, and physical absorption methods are employed in the other sweetening plants. Emissions data for sweetening processes other than amine types are very meager.

The major emission sources in the natural gas processing industry are compressor engines and acid gas wastes from gas sweetening plants. Compressor engine emissions are discussed in section 3.3.2; therefore, only gas sweetening plant emissions are discussed here.

9.2.2 Process Description[2,3]

Many chemical processes are available for sweetening natural gas. However, at present, the most widely used method for H_2S removal or gas sweetening is the amine type process (also known as the Girdler process) in which various amine solutions are utilized for absorbing H_2S. The process is summarized in reaction 1 and illustrated in Figure 9.2-2.

$$2\ RNH_2 + H_2S \longrightarrow (RNH_3)_2S \qquad (1)$$

where:
R = mono, di, or tri-ethanol
N = nitrogen
H = hydrogen
S = sulfur

The recovered hydrogen sulfide gas stream may be (1) vented, (2) flared in waste gas flares or modern smokeless flares, (3) incinerated, or (4) utilized for the production of elemental sulfur or other commercial products. If the recovered H_2S gas stream is not to be utilized as a feedstock for commercial applications, the gas is usually passed to a tail gas incinerator in which the H_2S is oxidized to sulfur dioxide and then passed to the atmosphere via a stack. For more details, the reader should consult Reference 8.

9.2.3 Emissions[4,5]

Emissions will only result from gas sweetening plants if the acid waste gas from the amine process is flared or incinerated. Most often, the acid waste gas is used as a feedstock in nearby sulfur recovery or sulfuric acid plants.

When flaring or incineration is practiced, the major pollutant of concern is sulfur dioxide. Most plants employ elevated smokeless flares or tail gas incinerators to ensure complete combustion of all waste gas constituents, including virtually 100 percent conversion of H_2S to SO_2. Little particulate, smoke, or hydrocarbons result from these devices, and because gas temperatures do not usually exceed 1200°F (650°C), significant quantities of nitrogen oxides are not formed. Emission factors for gas sweetening plants with smokeless flares or incinerators are presented in Table 9.2-1.

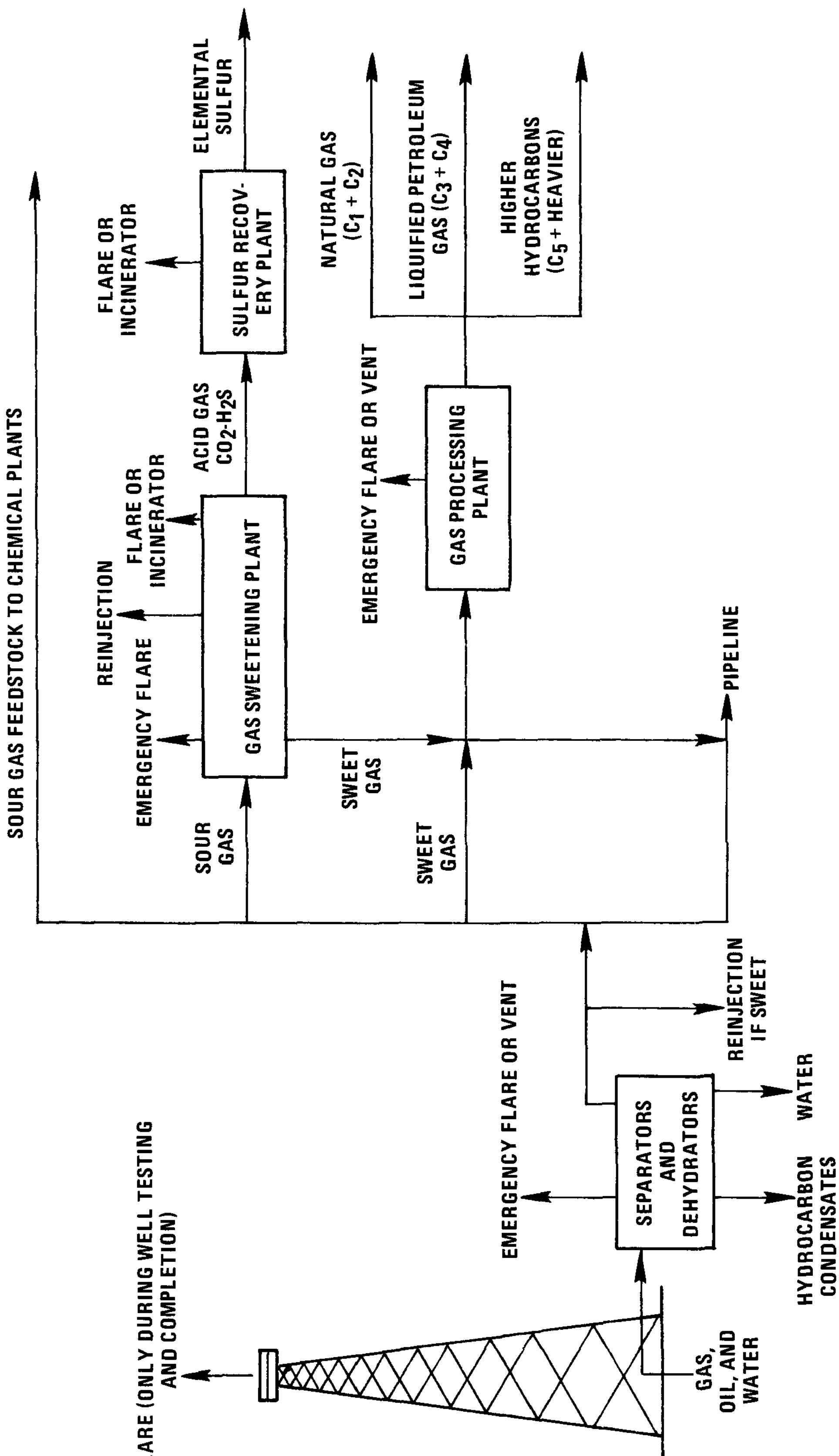

Figure 9.2-1. Generalized flow diagram of the natural gas industry.

Table 9.2-1. EMISSION FACTORS FOR GAS SWEETENING PLANTS[a]
EMISSION FACTOR RATING: SULFUR OXIDES: A
ALL OTHER FACTORS: C

Process[b]	Particulates	Sulfur oxides[c] (SO_2)	Carbon monoxide	Hydrocarbons	Nitrogen oxides
Amine					
lb/10^6 ft^3 gas processed	Neg.	1685 S[d]	Neg.	Neg.	Neg.
kg/10^3 m^3 gas processed	Neg.	26.98 S[d]	Neg.	Neg.	Neg.

[a]Emission factors are presented in this section only for smokeless flares and tail gas incinerators on the amine gas sweetening process. Too little emissions information exists to characterize emissions from older, less efficient waste gas flares on the amine process or from other, less common gas sweetening processes. Emission factors for various internal combustion engines utilized in a gas processing plant are given in section 3.3.2. Emission factors for sulfuric acid plants and sulfur recovery plants are given in sections 5.17 and 5.18, respectively.

[b]These factors represent emissions after smokeless flares (with fuel gas and steam injection) or tail gas incinerators and are based on References 2 and 4 through 7.

[c]These factors are based on the assumptions that virtually 100 percent of all H_2S in the acid gas waste is converted to SO_2 during flaring or incineration and that the sweetening process removes essentially 100 percent of the H_2S present in the feedstock.

[d]S is the H_2S content, on a mole percent basis, in the sour gas entering the gas sweetening plant. For example, if the H_2S content is 2 percent, the emission factor would be 1685 times 2, or 3370 lb SO_2 per million cubic feet of sour gas processed. If the H_2S mole percent is unknown, average values from Table 9.2-2 may be substituted.

Note: If H_2S contents are reported in grains per 100 scf or ppm, use the following factors to convert to mole percent:

0.01 mol % H_2S = 6.26 gr H_2S/100 scf at 60°F and 29.92 in. Hg

1 gr/100 scf = 16 ppm (by volume)

To convert to or from metric units, use the following factor:

0.044 gr/100 scf = 1 mg/Nm^3

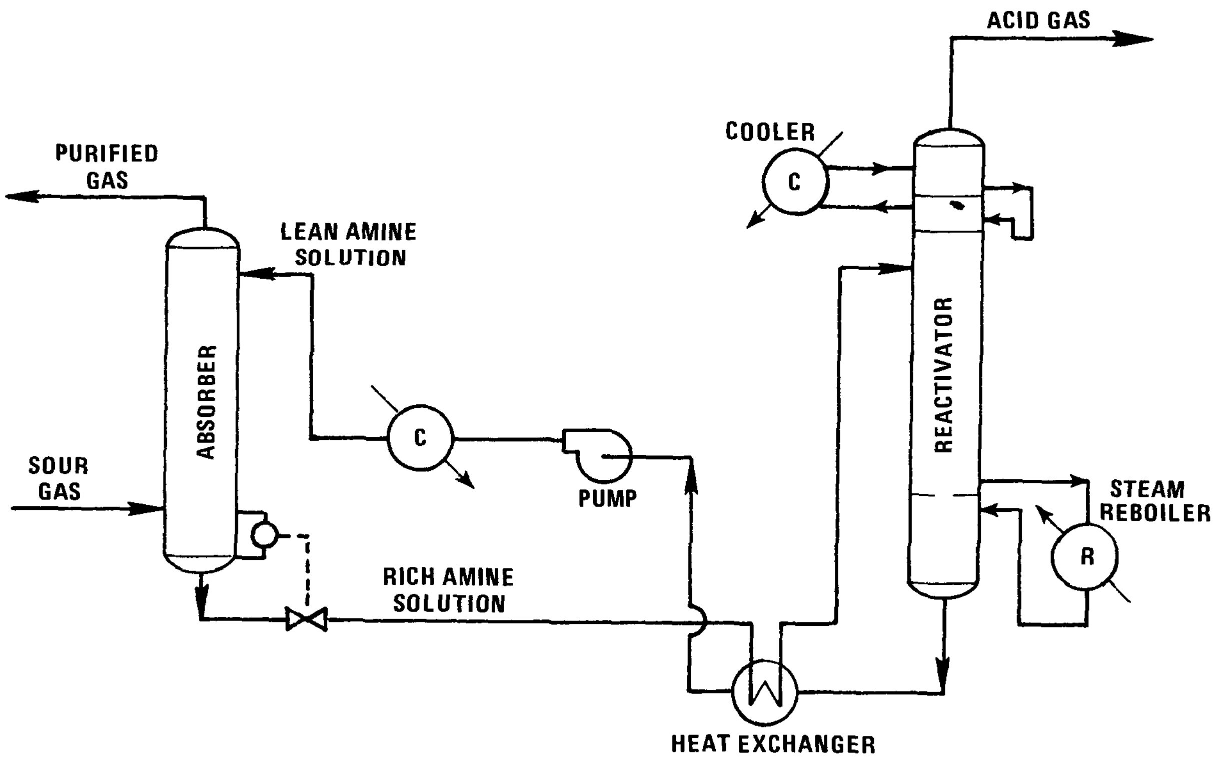

Figure 9.2-2. Flow diagram of the amine process for gas sweetening.

Table 9.2-2. AVERAGE HYDROGEN SULFIDE CONCENTRATIONS IN NATURAL GAS BY AIR QUALITY CONTROL REGION[a]

State	AQCR name	AQCR number	Average H_2S, mol %
Alabama	Mobile-Pensacola-Panama City - Southern Mississippi (Fla., Miss.)	5	3.30
Arizona	Four Corners (Colo., N.M., Utah)	14	0.71
Arkansas	Monroe-El Dorado (La.)	19	0.15
	Shreveport-Texarkana-Tyler (La., Okla., Texas)	22	0.55
California	Metropolitan Los Angeles	24	2.09
	San Joaquin Valley	31	0.89
	South Central Coast	32	3.66
	Southeast Desert	33	1.0
Colorado	Four Corners (Ariz., N.M., Utah)	14	0.71
	Metropolitan Denver	36	0.1
	Pawnee	37	0.49
	San Isabel	38	0.3
	Yampa	40	0.31
Florida	Mobile-Pensacola-Panama City - Southern Mississippi (Ala., Miss.)	5	3.30
Kansas	Northwest Kansas	97	0.005
	Southwest Kansas	100	0.02
Louisiana	Monroe-El Dorado (Ariz.)	19	0.15
	Shreveport-Texarkana-Tyler (Ariz., Okla., Texas)	22	0.55
Michigan	Upper Michigan	126	0.5
Mississippi	Mississippi Delta	134	0.68
	Mobile-Pensacola-Panama City - Southern Mississippi (Ala., Fla.)	5	3.30
Montana	Great Falls	141	3.93
	Miles City	143	0.4
New Mexico	Four Corners (Ariz., Colo., Utah)	14	0.71
	Pecos-Permian Basin	155	0.83
North Dakota	North Dakota	172	1.74[b]
Oklahoma	Northwestern Oklahoma	187	1.1
	Shreveport-Texarkana-Tyler (Ariz., La., Texas)	22	0.55
	Southeastern Oklahoma	188	0.3

Table 9.2-2 (continued). AVERAGE HYDROGEN SULFIDE CONCENTRATIONS IN NATURAL GAS BY AIR QUALITY CONTROL REGION[a]

State	AQCR name	AQCR number	Average H_2S, mol %
Texas	Abilene-Wichita Falls	210	0.055
	Amarillo-Lubbock	211	0.26
	Austin-Waco	212	0.57
	Corpus Christi-Victoria	214	0.59
	Metropolitan Dallas-Fort Worth	215	2.54
	Metropolitan San Antonio	217	1.41
	Midland-Odessa-San Angelo	218	0.63
	Shreveport-Texarkana-Tyler (Ariz., La., Okla.)	22	0.55
Utah	Four Corners (Ariz., Colo., N.M.)	14	0.71
Wyoming	Casper	241	1.262
	Wyoming (except Park, Bighorn and Washakie Counties)	243	2.34

[a]Reference 9.

[b]Sour gas only reported for Burke, Williams, and McKenzie Counties.

[c]Park, Bighorn, and Washakie Counties report gas with an average 23 mol % H_2S content.

Some plants still use older, less efficient waste gas flares. Because these flares usually burn at temperatures lower than necessary for complete combustion, some emissions of hydrocarbons and particulates as well as higher quantities of H_2S can occur. No data are available to estimate the magnitude of these emissions from waste gas flares.

Emissions from sweetening plants with adjacent commercial plants, such as sulfuric acid plants or sulfur recovery plants, are presented in sections 5.17 and 5.18, respectively. Emission factors for internal combustion engines used in gas processing plants are given in section 3.3.2.

Background material for this section was prepared for EPA by Ecology Audits, Inc.[8]

References for Section 9.2

1. Katz, D.L., D. Cornell, R. Kobayashi, F.H. Poettmann, J.A. Vary, J.R. Elenbaas, and C.F. Weinaug. Handbook of Natural Gas Engineering. New York, McGraw-Hill Book Company. 1959. 802 p.

2. Maddox, R.R. Gas and Liquid Sweetening. 2nd Ed. Campbell Petroleum Series, Norman, Oklahoma. 1974. 298 p.

3. Encyclopedia of Chemical Technology. Vol. 7. Kirk, R.E. and D.F. Othmer (eds.). New York, Interscience Encyclopedia, Inc. 1951.

4. Sulfur Compound Emissions of the Petroleum Production Industry. M.W. Kellogg Co., Houston, Texas. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-1308. Publication No. EPA-650/2-75-030. December 1974.

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6. Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration, Washington, D.C. Publication No. AP-68. March 1970. p. 3-1 and 4-5.

7. Control Techniques for Nitrogen Oxides from Stationary Sources. U.S. DHEW, PHS, EHS, National Air Pollution Control Administration, Washington, D.C. Publication No. AP-67. March 1970. p. 7-25 to 7-32.

8. Mullins, B.J. et al. Atmospheric Emissions Survey of the Sour Gas Processing Industry. Ecology Audits, Inc., Dallas, Texas. Prepared for Environmental Protection Agency, Research Triangle Park, N.C. under Contract No. 68-02-1865. Publication No. EPA-450/3-75-076. October 1975.

9. Federal Air Quality Control Regions. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. AP-102. January 1972.

10. WOOD PROCESSING

Wood processing involves the conversion of raw wood to either pulp, pulpboard, or one of several types of wallboard including plywood, particleboard, or hardboard. This section presents emissions data for chemical wood pulping, for pulpboard and plywood manufacturing, and for woodworking operations. The burning of wood waste in boilers and conical burners is not included as it is discussed in Chapters 1 and 2 of this publication.

10.1 CHEMICAL WOOD PULPING

Revised by Thomas Lahre

10.1.1 General[1]

Chemical wood pulping involves the extraction of cellulose from wood by dissolving the lignin that binds the cellulose fibers together. The principal processes used in chemical pulping are the kraft, sulfite, neutral sulfite semichemical (NSSC), dissolving, and soda; the first three of these display the greatest potential for causing air pollution. The kraft process accounts for about 65 percent of all pulp produced in the United States; the sulfite and NSSC processes, together, account for less than 20 percent of the total. The choice of pulping process is determined by the product being made, by the type of wood species available, and by economic considerations.

10.1.2 Kraft Pulping

10.1.2.1 Process Description[1,2]–The kraft process (see Figure 10.1.2-1) involves the cooking of wood chips under pressure in the presence of a cooking liquor in either a batch or a continuous digester. The cooking liquor, or "white liquor," consisting of an aqueous solution of sodium sulfide and sodium hydroxide, dissolves the lignin that binds the cellulose fibers together.

When cooking is completed, the contents of the digester are forced into the blow tank. Here the major portion of the spent cooking liquor, which contains the dissolved lignin, is drained, and the pulp enters the initial stage of washing. From the blow tank the pulp passes through the knotter where unreacted chunks of wood are removed. The pulp is then washed and, in some mills, bleached before being pressed and dried into the finished product.

It is economically necessary to recover both the inorganic cooking chemicals and the heat content of the spent "black liquor," which is separated from the cooked pulp. Recovery is accomplished by first concentrating the liquor to a level that will support combustion and then feeding it to a furnace where burning and chemical recovery take place.

Initial concentration of the weak black liquor, which contains about 15 percent solids, occurs in the multiple-effect evaporator. Here process steam is passed countercurrent to the liquor in a series of evaporator tubes that increase the solids content to 40 to 55 percent. Further concentration is then effected in the direct contact evaporator. This is generally a scrubbing device (a cyclonic or venturi scrubber or a cascade evaporator) in which hot combustion gases from the recovery furnace mix with the incoming black liquor to raise its solids content to 55 to 70 percent.

The black liquor concentrate is then sprayed into the recovery furnace where the organic content supports combustion. The inorganic compounds fall to the bottom of the furnace and are discharged to the smelt dissolving tank to form a solution called "green liquor." The green liquor is then conveyed to a causticizer where slaked lime (calcium hydroxide) is added to convert the solution back to white liquor, which can be reused in subsequent cooks. Residual lime sludge from the causticizer can be recycled after being dewatered and calcined in the hot lime kiln.

Many mills need more steam for process heating, for driving equipment, for providing electric power, etc., than can be provided by the recovery furnace alone. Thus, conventional industrial boilers that burn coal, oil, natural gas, and in some cases, bark and wood waste are commonly employed.

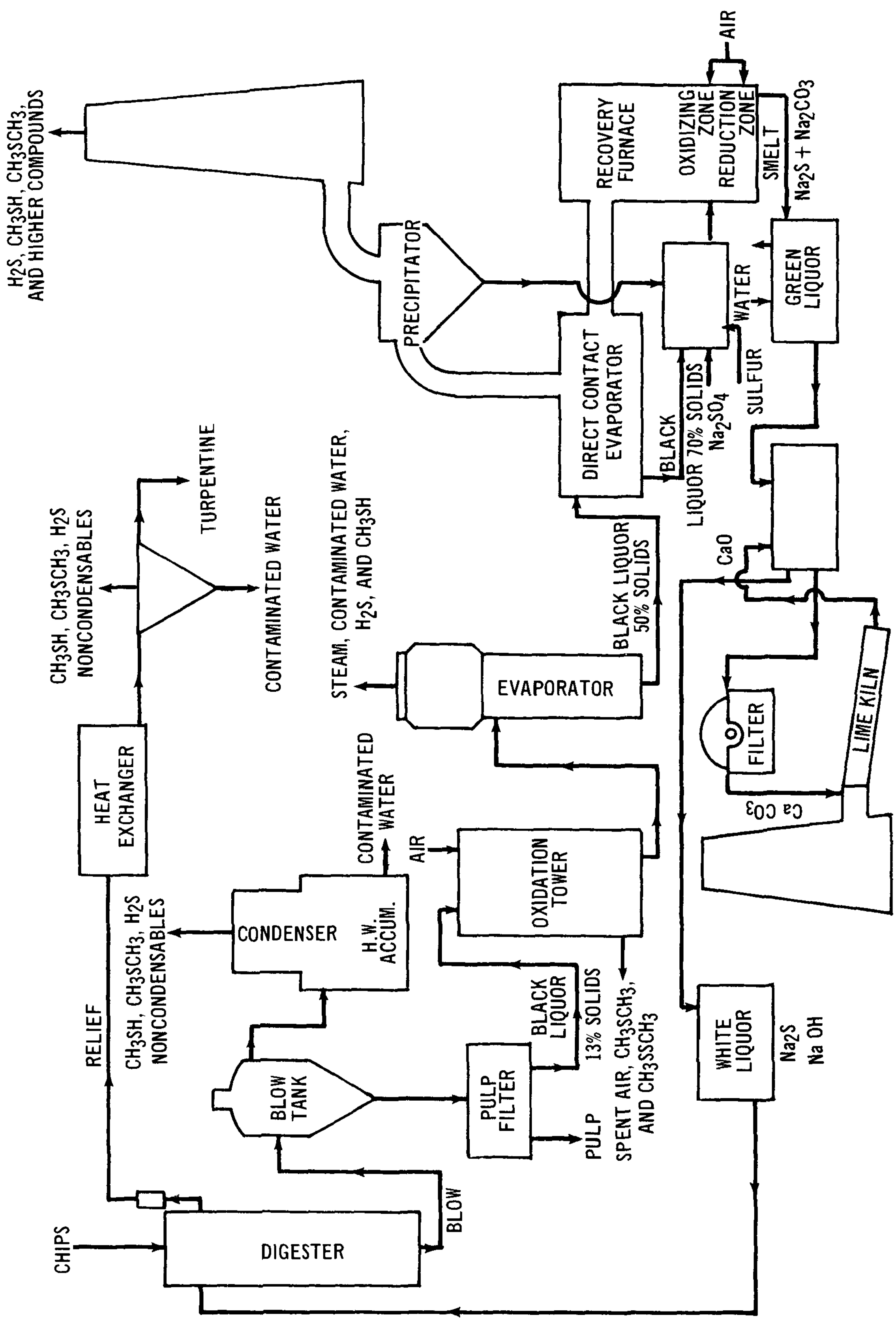

Figure 10.1.2-1. Typical kraft sulfate pulping and recovery process.

10.2 PULPBOARD

10.2.1 General[1]

Pulpboard manufacturing involves the fabrication of fibrous boards from a pulp slurry. This includes two distinct types of product, paperboard and fiberboard. Paperboard is a general term that describes a sheet 0.012 inch (0.30 mm) or more in thickness made of fibrous material on a paper-forming machine.[2] Fiberboard, also referred to as particle board, is thicker than paperboard and is made somewhat differently.

There are two distinct phases in the conversion of wood to pulpboard: (1) the manufacture of pulp from raw wood and (2) the manufacture of pulpboard from the pulp. This section deals only with the latter as the former is covered under the section on the wood pulping industry.

10.2.2 Process Description[1]

In the manufacture of paperboard, the stock is sent through screens into the head box, from which it flows onto a moving screen. Approximately 15 percent of the water is removed by suction boxes located under the screen. Another 50 to 60 percent of the moisture content is removed in the drying section. The dried board then enters the calendar stack, which imparts the final surface to the product.

In the manufacture of fiberboard, the slurry that remains after pulping is washed and sent to the stock chests where sizing is added. The refined fiber from the stock chests is fed to the head box of the board machine. The stock is next fed onto the forming screens and sent to dryers, after which the dry product is finally cut and fabricated.

10.2.3 Emissions[1]

Emissions from the paperboard machine consist mainly of water vapor; little or no particulate matter is emitted from the dryers.[3-5] Particulates are emitted, however, from the fiberboard drying operation. Additional particulate emissions occur from the cutting and sanding operations. Emission factors for these operations are given in section 10.4. Emission factors for pulpboard manufacturing are shown in Table 10.2-1.

Table 10.2-1. PARTICULATE EMISSION FACTORS FOR PULPBOARD MANUFACTURING[a]
EMISSION FACTOR RATING: E

Type of product	Emissions	
	lb/ton	kg/MT
Paperboard	Neg	Neg
Fiberboard[b]	0.6	0.3

[a]Emission factors expressed as units per unit weight of finished product.
[b]Reference 1.

References for Section 10.2

1. Air Pollutant Emission Factors. Resources Research, Inc., Reston, Virginia. Prepared for National Air Pollution Control Administration, Washington, D.C. under Contract No. CPA-22-69-119. April 1970.

2. The Dictionary of Paper. New York, American Paper and Pulp Association, 1940.

3. Hough, G. W. and L. J. Gross. Air Emission Control in a Modern Pulp and Paper Mill. Amer. Paper Industry. *51*:36, February 1969.

4. Pollution Control Progress. J. Air Pollution Control Assoc. *17*:410, June 1967.

5. Private communication between I. Gellman and the National Council of the Paper Industry for Clean Air and Stream Improvement. New York, October 28, 1969.

10.3 PLYWOOD VENEER AND LAYOUT OPERATIONS

By Thomas Lahre

10.3.1 Process Description[1]

Plywood is a material made of several thin wood veneers bonded together with an adhesive. Its uses are many and include wall sidings, sheathing, roof-decking, concrete-formboards, floors, and containers.

During the manufacture of plywood, incoming logs are sawed to desired length, debarked, and then peeled into thin, continuous veneers of uniform thickness. (Veneer thicknesses of 1/45 to 1/5 inch are common.) These veneers are then transported to special dryers where they are subjected to high temperatures until dried to a desired moisture content. After drying, the veneers are sorted, patched, and assembled in layers with some type of thermosetting resin used as the adhesive. The veneer assembly is then transferred to a hot press where, under presssure and steam heat, the plywood product is formed. Subsequently, all that remains is trimming, sanding, and possibly some sort of finishing treatment to enhance the usefullness of the plywood.

10.3.2 Emissions[2,3]

The main sources of emissions from plywood manufacturing are the veneer drying and sanding operations. A third source is the pressing operation although these emissions are considered minor.

The major pollutants emitted from veneer dryers are organics. These consist of two discernable fractions: (1) condensibles, consisting of wood resins, resin acids, and wood sugars, which form a blue haze upon cooling in the atmosphere, and (2) volatiles, which are comprised of terpines and unburned methane–the latter occurring when gas-fired dryers are employed. The amounts of these compounds produced depends on the wood species dried, the drying time, and the nature and operation of the dryer itself. In addition, negligible amounts of fine wood fibers are also emitted during the drying process.

Sanding operations are a potential source of particulate emissions (see section 10.4). Emission factors for plywood veneer dryers without controls are given in Table 10.3-1.

Table 10.3-1. EMISSION FACTORS FOR PLYWOOD MANUFACTURING
EMISSION FACTOR RATING: B

Source	Organic compound[a,b]			
	Condensible		Volatile	
	$lb/10^4\ ft^2$	$kg/10^3\ m^2$	$lb/10^4\ ft^2$	$kg/10^3\ m^2$
Veneer dryers	3.6	1.9	2.1	1.1

[a]Emission factors expressed in pounds of pollutant per 10,000 square feet of 3/8-in. plywood produced (kilograms per 1,000 square meters on a 1-cm basis).

[b]References 2 and 3.

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10.4 WOODWORKING OPERATIONS

by Tom Lahre

10.4.1 General [1-5]

"Woodworking," as defined in this section, includes any operation that involves the generation of small wood waste particles (shavings, sanderdust, sawdust, etc.) by any kind of mechanical manipulation of wood, bark, or wood byproducts. Common woodworking operations include sawing, planing, chipping, shaping, moulding, hogging, latheing, and sanding. Woodworking operations are found in numerous industries such as sawmills; plywood, particleboard, and hardboard plants; and furniture manufacturing plants.

Most plants engaged in woodworking employ pneumatic transfer systems to remove the generated wood waste from the immediate proximity of each woodworking operation. These systems are necessary as a housekeeping measure to eliminate the vast quantity of waste material that would otherwise accumulate. They are also a convenient means of transporting the waste material to common collection points for ultimate disposal. Large diameter cyclones have historically been the primary means of separating the waste material from the airstreams in the pneumatic transfer systems, although baghouses have recently been installed in some plants for this purpose.

The waste material collected in the cyclones or baghouses may be burned in wood waste boilers, utilized in the manufacture of other products (such as pulp or particleboard), or incinerated in conical (teepee/wigwam) burners. The latter practice is declining with the advent of more stringent air pollution control regulations and because of the economic attractiveness of utilizing wood waste as a resource.

10.4.2 Emissions[1-6]

The only pollutant of concern in woodworking operations is particulate matter. The major emission points are the cyclones utilized in the pneumatic transfer systems. The quantity of particulate emissions from a given cyclone will depend on the dimensions of the cyclone, the velocity of the airstream, and the nature of the operation generating the waste. Typical large-diameter cyclones found in the industry will only effectively collect particles greater than 40 micrometers in diameter. Baghouses, when employed, collect essentially all of the waste material in the airstream.

It is difficult to describe a typical woodworking operation and the emissions resulting therefrom because of the many types of operations that may be required to produce a given type of product and because of the many variations that may exist in the pneumatic transfer and collection systems. For example, the waste from numerous pieces of equipment often feed into the same cyclone, and it is common for the material collected in one or several cyclones to be conveyed to another cyclone. It is also possible for portions of the waste generated by a single operation to be directed to different cyclones.

Because of this complexity, it is useful when evaluating emissions from a given facility to consider the waste handling cyclones as air pollution sources instead of the various woodworking operations that actually generate the particulate matter. Emission factors for typical large-diameter cyclones utilized for waste collection in woodworking operations are given in Table 10.4-1.

Emission factors for wood waste boilers, conical burners, and various drying operations—often found in facilities employing woodworking operations—are given in sections 1.6, 2.3, 10.2, and 10.3.

Table 10.4.1. PARTICULATE EMISSION FACTORS FOR LARGE DIAMETER CYCLONES[a] IN WOODWORKING INDUSTRY

Types of waste handled	Particulate emissions[b]			
	gr/scf	g/Nm^3	lb/hr	kg/hr
Sanderdust[c]	0.055[d]	0.126[d]	5[e]	2.3[e]
Other[f]	0.03[g]	0.07[g]	2[h]	0.91[h]

[a]Typical waste collection cyclones range from 4 to 16 feet (1.2 to 4.9 meters) in diameter and employ airflows ranging from 2,000 to 26,000 standard cubic feet (57 to 740 normal cubic meters) per minute. Note: if baghouses are used for waste collection, particulate emissions will be negligible.

[b]Based on information in References 1 through 3.

[c]These factors should be used whenever waste from sanding operations is fed directly into the cyclone in question.

[d]These factors represent the median of all values observed. The observed values range from 0.005 to 0.16 gr/scf (0.0114 to 0.37 g/Nm^3).

[e]These factors represent the median of all values observed. The observed values range from 0.2 to 30 lb/hr (0.09 to 13.6 kg/hr).

[f]These factors should be used for cyclones handling waste from all operations other than sanding. This includes cyclones that handle waste (including sanderdust) already collected by another cyclone.

[g]These factors represent the median of all values observed. The observed values range from 0.001 to 0.16 gr/scf (0.002 to 0.37 g/Nm^3).

[h]These factors represent the median of all values observed. The observed values range from 0.03 to 24 lb/hr (0.014 to 10.9 kg/hr).

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6. ABSTRACT

In this supplement for Compilation of Air Pollutant Emission Factors (AP-42) revised and updated emissions data are presented for fuel oil combustion, open burning, heavy-duty, natural-gas-fired pipeline compressor engines, alfalfa dehydrating, sugar cane processing, natural gas processing, and woodworking operations.

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