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SUPPLEMENT C

TO

**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
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Volume I
Supplement C

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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.

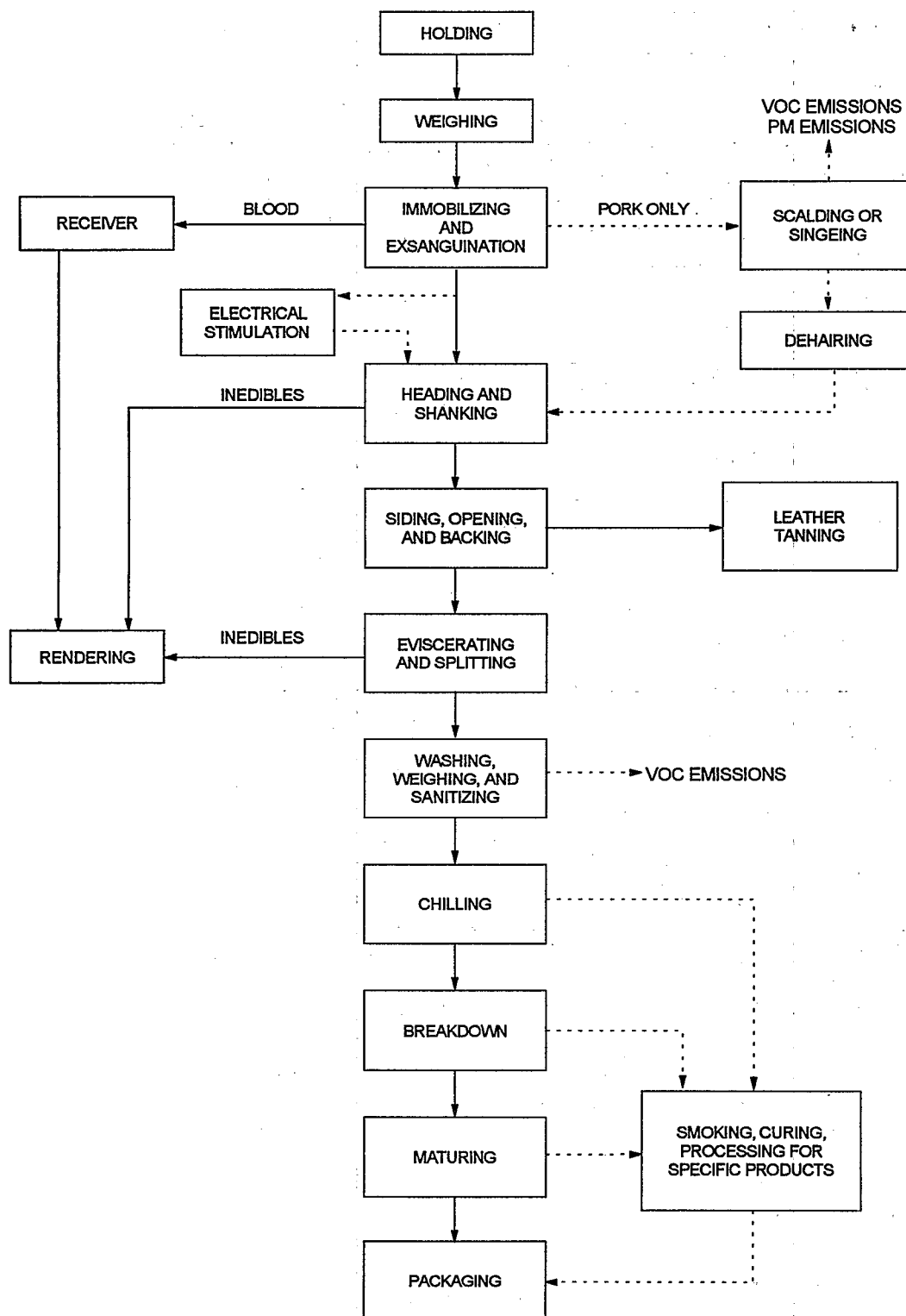
9.5.1.2.1 Beef Processing³⁻⁷ -

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°C (32°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°C [27°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°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 CO₂, 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.

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° to 149°C [250° to 300°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 hand-skinned, 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°C (32° to 34°F) with air velocity typically 5 to 15 mph, equating to -5°C (23°F) wind chill, for a 24-hour chill period. For thorough chilling, the inside temperature of the ham should reach at least 3°C (37°F). With accelerated (hot) processing, the carcass may be held (tempered) at an intermediate temperature of 16°C (60°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°C (27°F), bringing the wind chill to -9°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 as 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 sorbents, 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

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 CO₂, 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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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.

Table 9.6.1-1. DIFFERENCES IN SELECTED CHEESEMAKING STEPS

Type of Cheese	Primary Coagulating Agent/Time	Cooking Temp. °C (°F)	Primary Draining Method	pH	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)	Hoop	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)	Hoop	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

Source: Reference 8

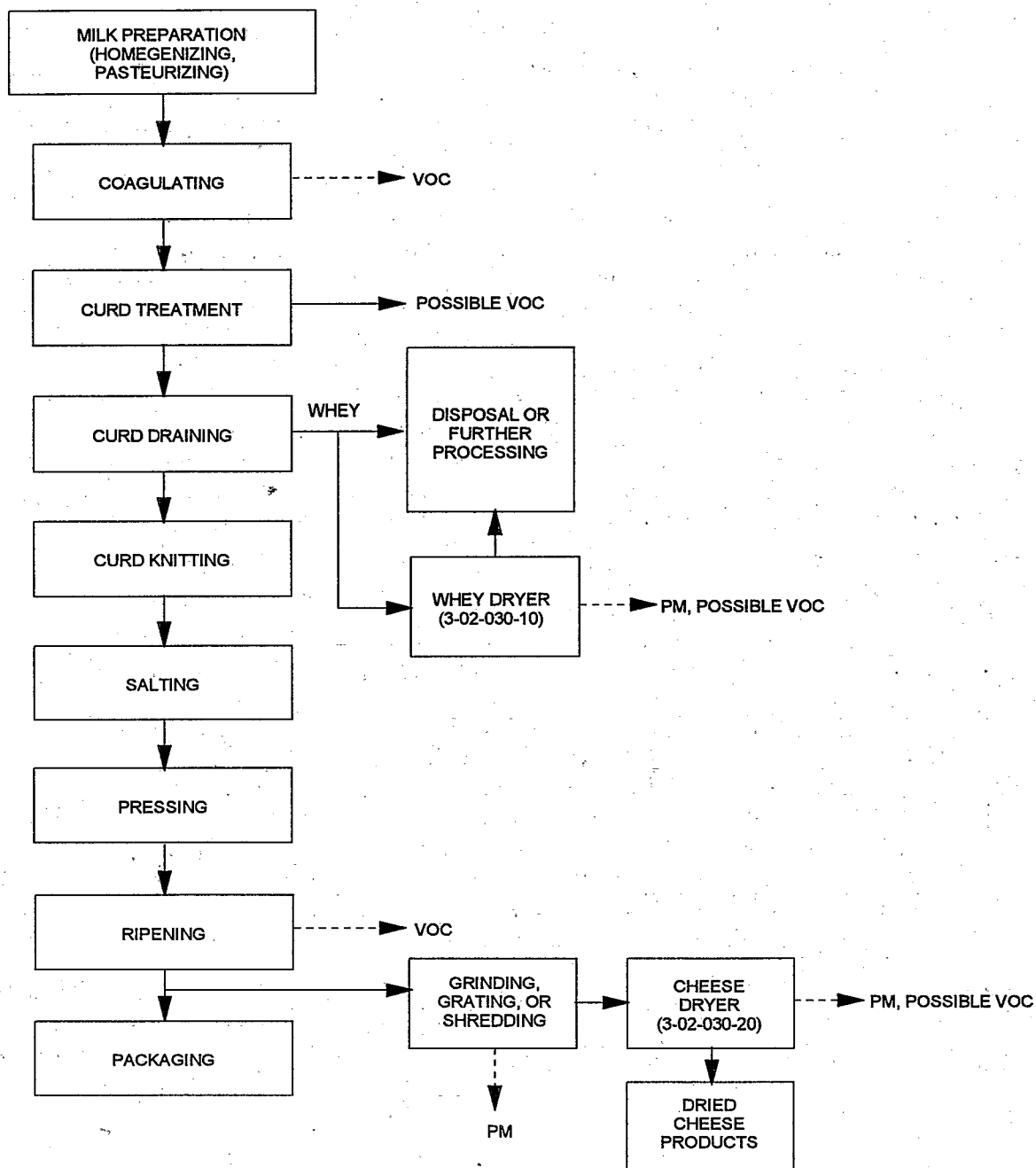


Figure 9.6.1-1. Natural cheese manufacture.
(Source Classification Code in parentheses.)

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.

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. CO₂ 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.

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

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

^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.

References For Section 9.6.1

1. 1992 *Census Of Manufactures: Dairy Products*, U. S. Department of Commerce, Bureau of Census, Washington, DC, 1994.
2. U. S. Department of Agriculture, National Agriculture Statistics Service, *Dairy Products 1995 Summary*, Washington, DC, April 1996. <http://usda.mannlib.cornell.edu/reports>
3. B. Battistotti, et al., *Cheese: A Guide To The World Of Cheese And Cheesemaking*, Facts On File Publications, NY, 1984.
4. A. Eck, ed., *Cheesemaking: Science And Technology*, Lavoisier Publishing, New York, 1987.
5. A. Meyer, *Processed Cheese Manufacture*, Food Trade Press Ltd., London, 1973.
6. *Newer Knowledge Of Cheese And Other Cheese Products*, National Dairy Council, Rosemont, IL, 1992.
7. M.E. Schwartz, *Cheesemaking Technology*, Noyes Data Corporation, Park Ridge, NJ, 1973.
8. F. Kosikowski, *Cheese And Fermented Milk Foods*, Edwards Brothers, Ann Arbor, MI, 1977.
9. New Standard Encyclopedia, Vol.4, "Cheese", Standard Educational Corporation, Chicago, IL, pp. 238-240.



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:

$$\text{VOC E.F.} = 0.95Y_i + 0.195t_i - 0.51S - 0.86t_s + 1.90$$

where

- VOC E.F. = pounds VOC per ton of baked bread
- Y_i = initial baker's percent of yeast
- t_i = total yeast action time in hours
- S = final (spike) baker's percent of yeast
- t_s = 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.



9.10.1.1 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.

References For Section 9.10.1.1

1. "Sugar Cane," In: *Kirk-Othmer Encyclopedia Of Chemical Technology*, Vol. IX, New York, John Wiley and Sons, Inc., 1964.
2. E. F. Darley, "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, California, Prepared for the U. S. Environmental Protection Agency, Research Triangle Park, NC, under Grant No. R800711, August 1974.
3. *Background Information For Establishment Of National Standards Of Performance For New Sources*, Raw Cane Sugar Industry, Environmental Engineering, Inc., Gainesville, FL, Prepared for the U. S. Environmental Protection Agency, Research Triangle Park, NC, under Contract No. CPA 70-142, Task Order 9c, July 15, 1971.



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 denaturation 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.

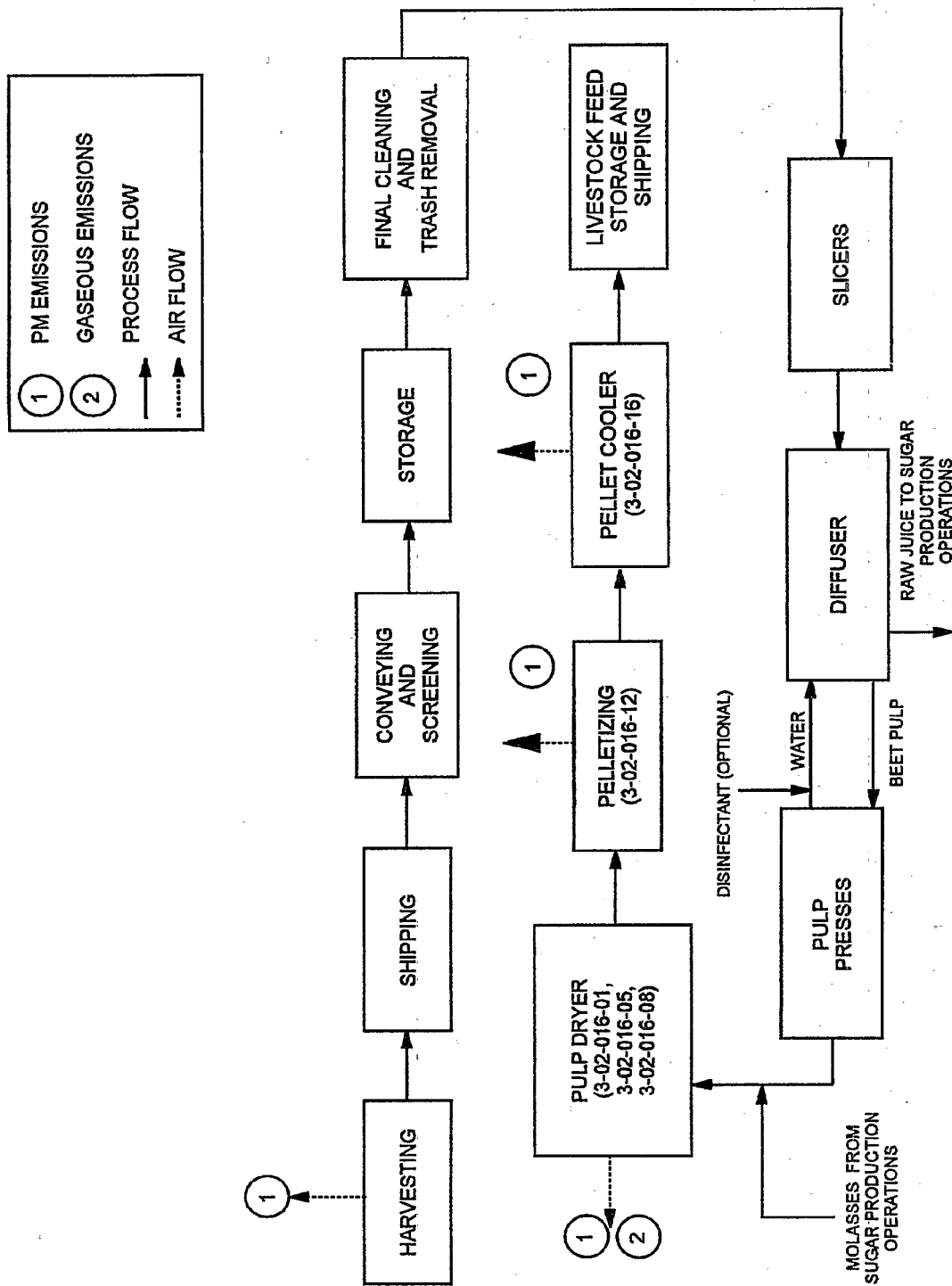


Figure 9.10.1.2-1. Preprocessing and livestock feed production operations at a sugarbeet processing plant.
(Source Classification Code in parentheses.)

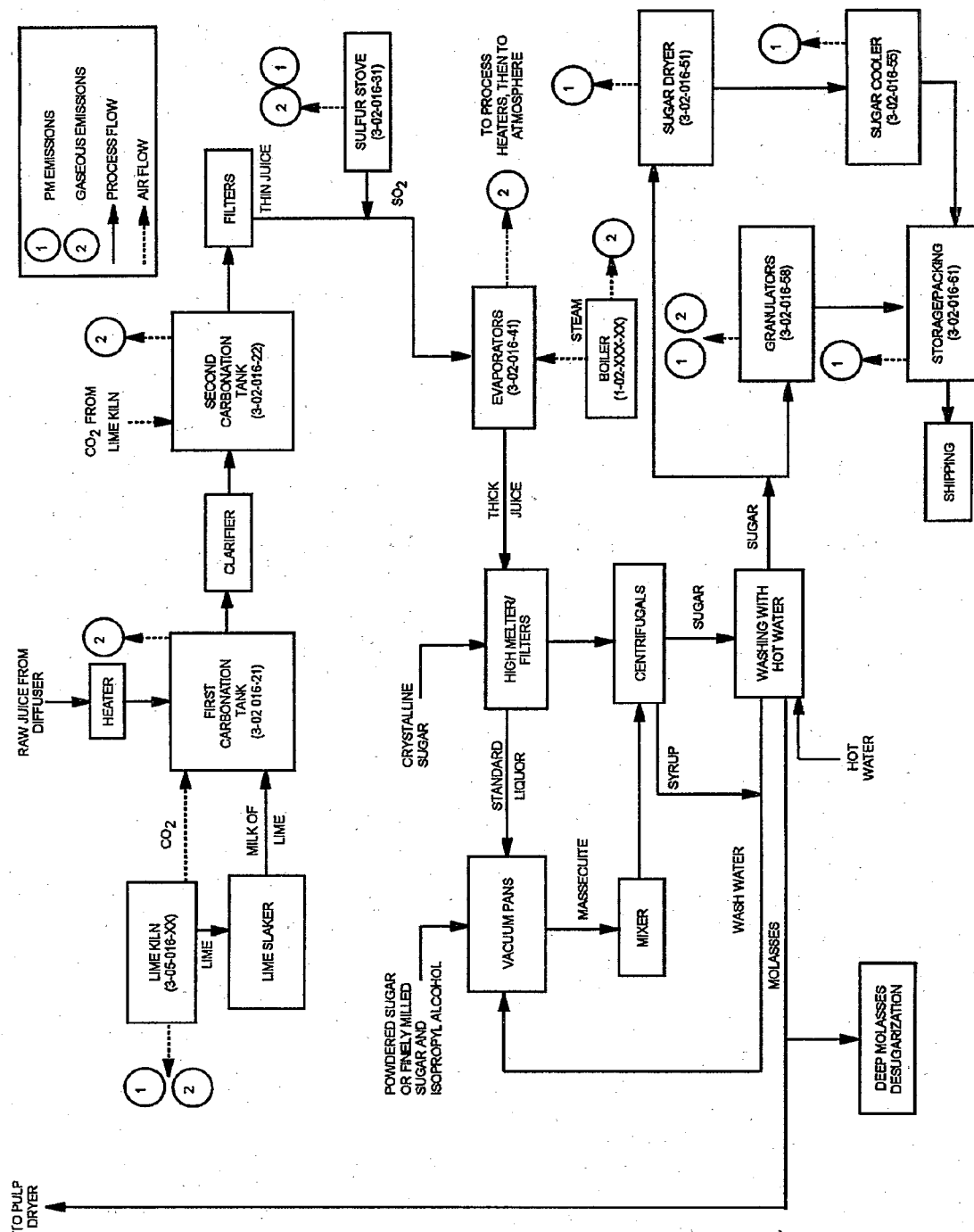


Figure 9.10.1.2-2. Sugar production operations at a sugarbeet processing plant.
(Source Classification Code in parentheses.)

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 $[\text{Ca}(\text{OH})_2]$ 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 evaporators, and this steam is used as a heat source for various process heaters throughout the plant. After 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

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 CO₂, 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, SO₂, CO, and CO₂ 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.

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

Source	Type of Control	Filterable PM				Condensable PM			
		PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Coal-fired pulp dryer ^b (SCC 3-02-016-01)	None	4.4	D	ND		ND		ND	ND
	Multiclone	0.66 ^c	B	ND		ND		0.084 ^d	C
Natural gas-fired pulp dryer (SCC 3-02-016-08)	Wet scrubber	0.49	D	ND		0.050 ^f	D	0.35 ^e	D
	Multiclone ^h	0.69	D	ND		ND		ND	ND
	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	C	ND		0.24 ⁿ	C	0.076 ^m	C
	Dry scrubber and cyclone	1.1	D	0.83 ^p	D	0.24 ⁿ	C	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
	Mechanical centrifugal separator with water sprays ^r	0.13	D	ND		ND		0.0043	D
Sugar conveying and sacking (SCC 3-02-016-61)	Venturi scrubber ^s	0.065	D	ND		0.0047	D	0.0042	D
	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

Table 9.10.1.2-1 (cont.).

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

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

EMISSION FACTOR RATING: D

Source	lb/ton					
	VOC ^b	Methane	NO _x	SO ₂	CO	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

- ^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 FACTOR RATING: E

Source	Pollutant		Emission Factor, lb/ton
	CASRN	Name	
Coal-fired pulp dryer with wet scrubber (SCC 3-02-016-01)	75-07-0	Acetaldehyde	0.015
	107-02-8	Acrolein	0.0076
	123-73-9	Crotonaldehyde	0.0020
	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

^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.

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

Source	Pollutant		Emission Factor, lb/1,000 gal	EMISSION FACTOR RATING
	CASRN	Name		
First carbonation tank ^b (SCC 3-02-016-21)	91-57-6	2-methylnaphthalene	5.1×10^{-7}	D
	51-28-5	2,4-dinitrophenol	ND	D
	106-44-5	4-methylphenol	6.6×10^{-7}	D
	83-32-9	Acenaphthene	ND	D
	100-52-7	Benzaldehyde	1.1×10^{-4}	D
	65-85-0	Benzoic acid	8.4×10^{-6}	D
	100-51-6	Benzyl alcohol	5.0×10^{-6}	D
	117-81-7	Bis(2-ethylhexyl)phthalate	1.2×10^{-5}	D
	91-20-3	Naphthalene	2.0×10^{-6}	D
	85-01-8	Phenanthrene	1.4×10^{-6}	D
	108-95-2	Phenol	1.3×10^{-6}	D
Second carbonation tank ^b (SCC 3-02-016-22)	75-07-0	Acetaldehyde	0.0043	E
	107-02-8	Acrolein	2.4×10^{-4}	E
	123-73-9	Crotonaldehyde	3.0×10^{-5}	E
	50-00-0	Formaldehyde	1.6×10^{-5}	E
First evaporator ^c (SCC 3-02-016-41)	75-07-0	Acetaldehyde	6.7×10^{-5}	E
	107-02-8	Acrolein	4.2×10^{-7}	E
	123-73-9	Crotonaldehyde	1.4×10^{-7}	E
	50-00-0	Formaldehyde	7.0×10^{-7}	E
	106-44-5	4-methylphenol	ND	E
	100-52-7	Benzaldehyde	2.2×10^{-6}	E
	65-85-0	Benzoic acid	ND	E
	100-51-6	Benzyl alcohol	1.8×10^{-7}	E
	117-81-7	Bis(2-ethylhexyl)phthalate	3.7×10^{-7}	E
	84-74-2	Di-n-butylphthalate	1.1×10^{-9}	E
	132-64-9	Dibenzofuran	ND	E
	84-66-2	Diethylphthalate	ND	E
	78-59-1	Isophorone	ND	E
	91-20-3	Naphthalene	2.5×10^{-8}	E
	85-01-8	Phenanthrene	1.6×10^{-8}	E
	108-95-2	Phenol	1.2×10^{-8}	E
	110-86-1	Pyridine	3.4×10^{-8}	E

^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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9.12.3 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 -

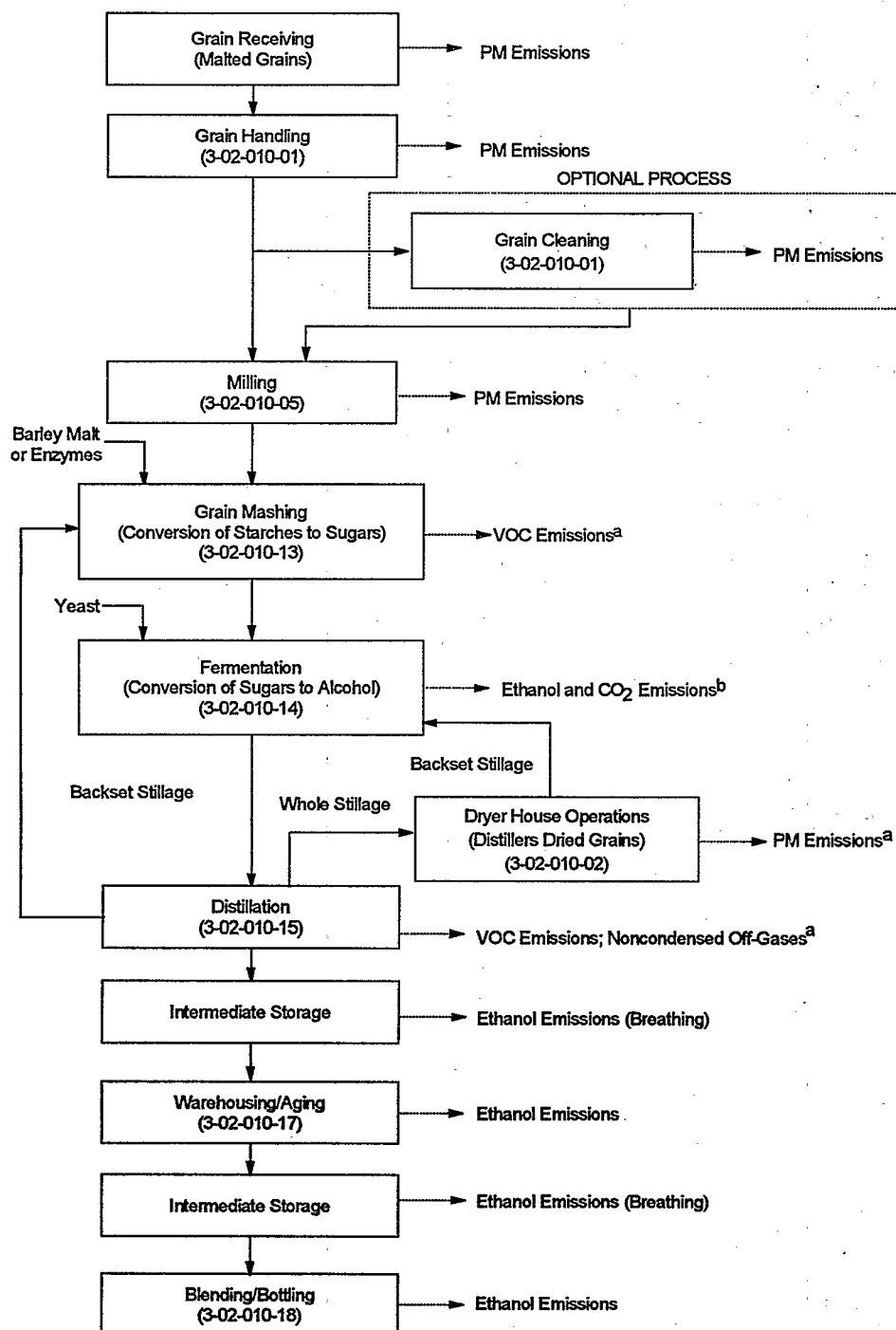
Distilleries utilize premium cereal grains, such as hybrid corn, rye, barley, and wheat, to produce the various types of whisky and other distilled spirits. Grain is received at a distillery from a grain-handling facility and is prepared for fermentation by milling or by malting (soaking the grains to 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).

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 temperatures increase the rate of extraction, transfer by diffusion, and reaction. Diurnal and seasonal 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

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

EMISSION FACTOR RATING: E

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

^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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9.15 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

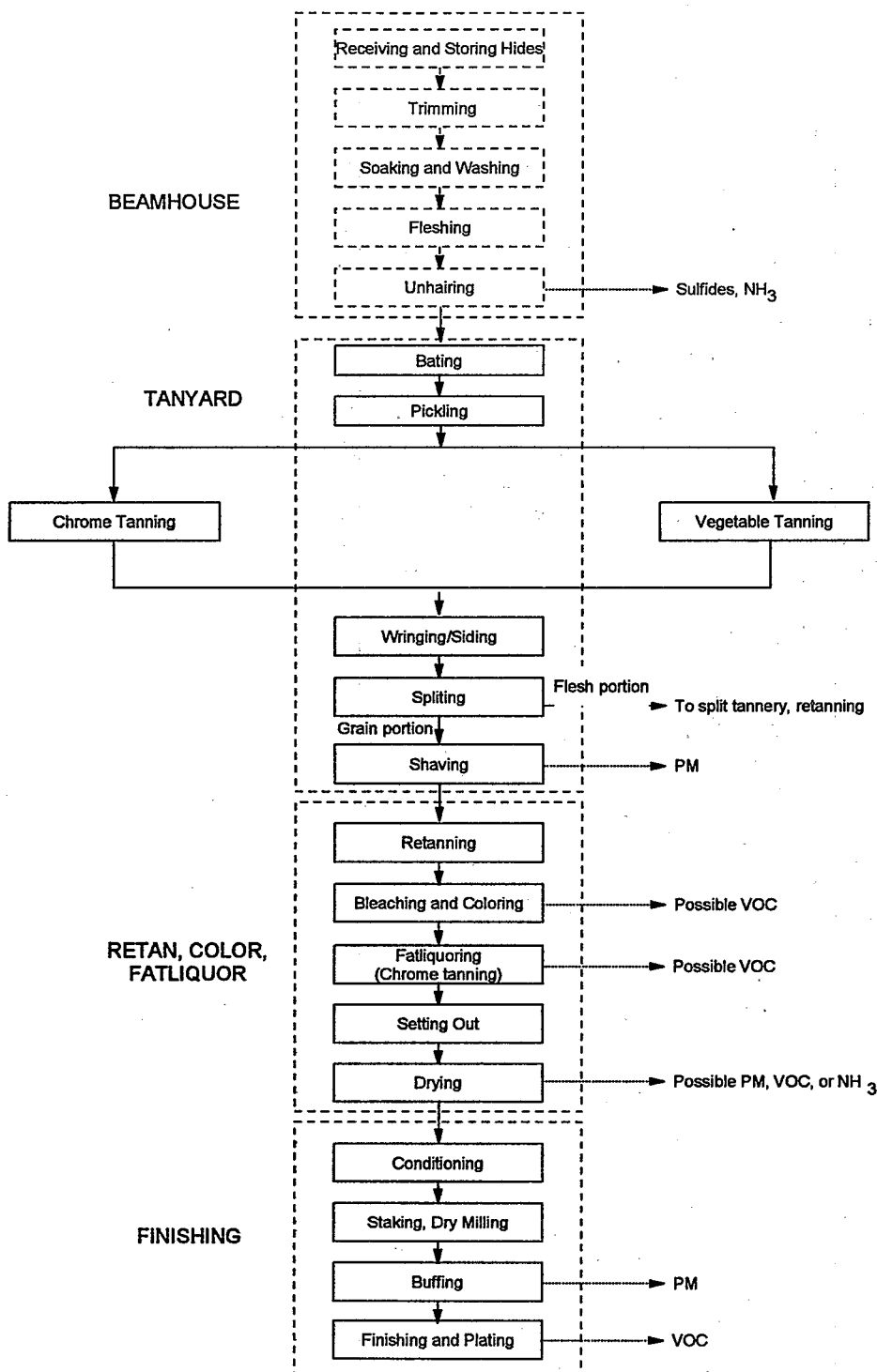


Figure 9.15-1. General flow diagram for leather tanning and finishing process.

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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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).

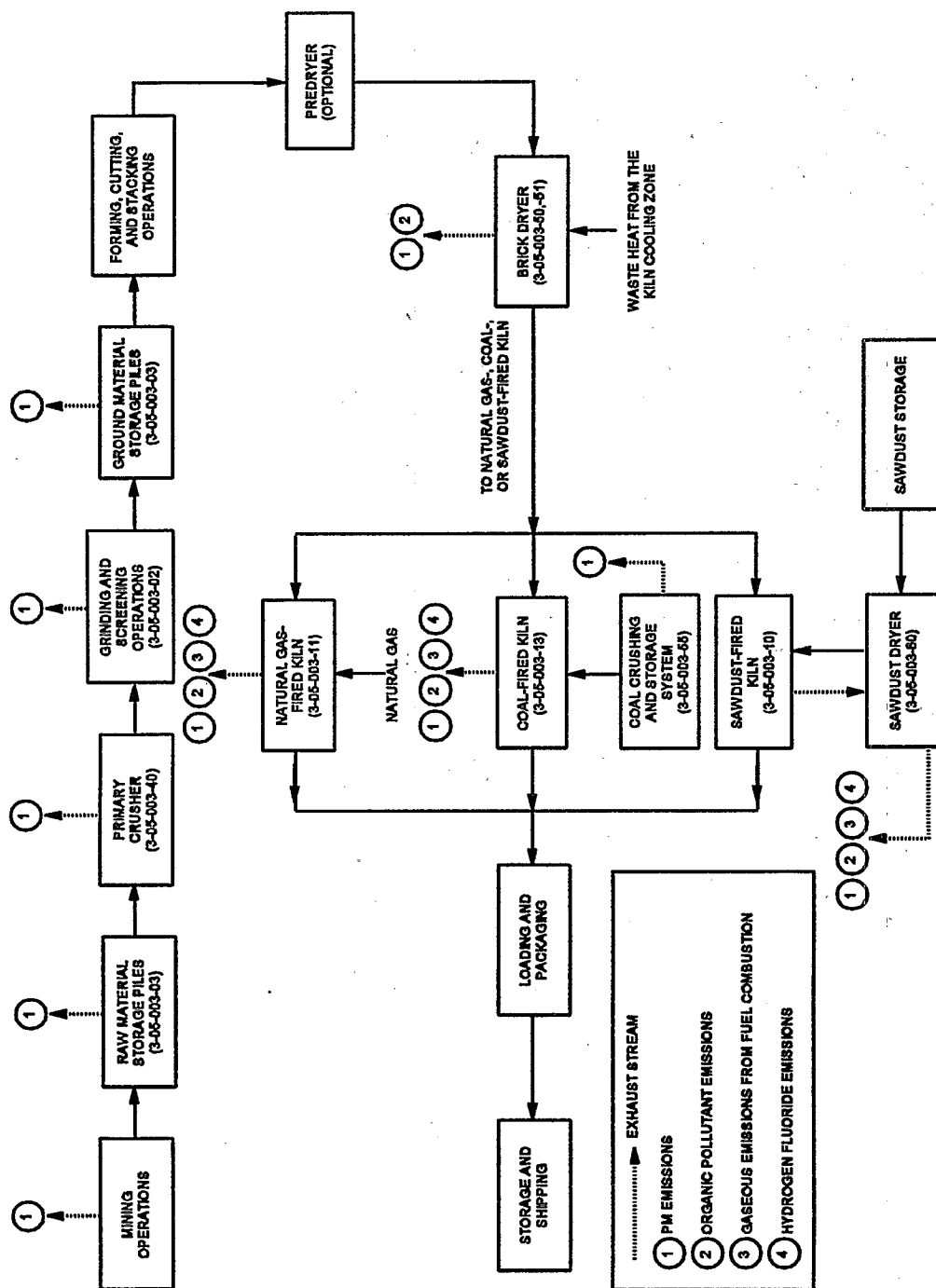


Figure 11.3-1. Typical brick manufacturing process.
(Source Classification Codes in parentheses.)

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 SO₂, NO_x, CO, and CO₂, 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 SO₂ 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 SO₂ emissions than facilities that use low-sulfur raw material. In addition, some facilities use additives that contain sulfates, and these additives may contribute to SO₂ 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° to 600°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 SO₂ and PM emissions. In addition, research is being performed on the use of additives (such as lime) to reduce HF and SO₂ 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.

Table 11.3-1. PARTICULATE MATTER EMISSION FACTORS FOR BRICK MANUFACTURING OPERATIONS^a

Source	Filterable PM ^b						Condensible PM ^c			
	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	E	ND	NA	NA	NA	NA	NA
Grinding and screening operations (SCC 3-05-003-02)										
	0.025	E	0.0023	E	ND	NA	NA	NA	NA	NA
	8.5	E	0.53	E	ND	NA	NA	NA	NA	NA
	0.0062	E	0.0032	E	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
	0.077 ^j	E	ND	NA	ND	NA	0.11 ^k	E	ND	NA
Brick dryer (SCC 3-05-003-50, -51)	0.37 ^m	C	0.28 ⁿ	E	ND	NA	0.48 ^p	D	0.11 ^q	D
Natural gas-fired kiln (SCC 3-05-003-11)										
Coal-fired kiln (SCC 3-05-003-13)										
	1.2 ^r	A	0.76 ^s	C	0.28 ^t	D	0.48 ^p	D	0.11 ^q	D
	0.043 ^v	E	ND	NA	ND	NA	0.48 ^u	D	0.11 ^q	D
	0.34 ^w	D	0.26 ^x	D	0.16 ^x	D	0.48 ^p	D	0.11 ^q	D
Sawdust-fired kiln (SCC 3-05-003-10)										
Sawdust-fired kiln and sawdust dryer ^y (SCC 3-05-003-61)	1.3	E	0.25	E	ND	NA	0.013	E	0.043	E
Natural gas-fired kiln firing structural clay tile ^z (SCC 3-05-003-70)	1.0	E	ND	NA	ND	NA	ND	NA	ND	NA

^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-10 and condensible inorganic and organic 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.

Table 11.3-1. (cont.).

- 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.

Table 11.3-2. EMISSION FACTORS FOR TOTAL PM, TOTAL PM-10, AND TOTAL PM-2.5 FROM BRICK MANUFACTURING OPERATIONS^a

Source	Total PM ^b					
	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	PM-2.5	EMISSION FACTOR RATING
Primary crusher with fabric filter (SCC 3-05-003-40)	ND	NA	0.00059	E	ND	NA
Grinding and screening operations (SCC 3-05-003-02)						
processing dry material ^c	8.5	E	0.53	E	ND	NA
processing wet material ^d	0.025	E	0.0023	E	ND	NA
with fabric filter ^e	0.0062	E	0.0032	E	ND	NA
Extrusion line with fabric filter ^f (SCC 3-05-003-42)	ND	NA	0.0036	E	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	B	1.4	C	0.87	D
with fabric filter	0.63	E	ND	NA	ND	NA
Sawdust-fired kiln (SCC 3-05-003-10)	0.93	D	0.85	D	0.75	D
Sawdust-fired kiln and sawdust dryer ^g (SCC 3-05-003-61)	1.4	E	0.31	E	ND	NA

^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.

Table 11.3-3. EMISSION FACTORS FOR BRICK MANUFACTURING OPERATIONS^a

Source	SO ₂ ^b	EMISSION FACTOR RATING	SO ₃	EMISSION FACTOR RATING	NO _x	EMISSION FACTOR RATING	CO	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	E	71 ^f	E
Natural gas-fired kiln (SCC 3-05-003-11)	0.67 ^g	C	0.11 ^h	D	0.35 ^j	C	1.2 ^k	C	400 ^m	B
Natural gas-fired kiln firing high-sulfur material ⁿ (SCC 3-05-003-22)										
uncontrolled	5.1 ^p	D	ND	NA	0.35 ^j	C	1.2 ^k	C	400 ^m	B
with medium-efficiency wet scrubber ^q	1.0 ^q	C	ND	NA	0.35 ^j	C	1.2 ^k	C	400 ^m	B
with high-efficiency packed-bed scrubber ^r	0.0049 ^r	C	ND	NA	0.35 ^j	C	1.2 ^k	C	400 ^m	B
Coal-fired kiln (SCC 3-05-003-13)	1.2 ^s	D	ND	NA	0.51 ^t	D	0.80 ^t	D	300 ^u	C
Sawdust-fired kiln (SCC 3-05-003-10)	0.67 ^g	C	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, SO₂ emissions can be more accurately estimated using mass balance procedures. Assuming that all of the sulfur in the raw material is released as SO₂ during firing, each lb of sulfur in the raw material will result in 2 lb of SO₂ emissions. The amount of SO₂ 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 SO₃ emissions are generally a small percentage of total sulfur oxide (SO_x) emissions, assume that all SO_x is SO₂ when performing mass balance calculations. For coal-fired kilns, the contribution of the coal to SO₂ emissions must also be accounted for when performing mass balance calculations.

Table 11.3-3. (cont.).

- ^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 CO_2 . 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 CO_2 .
- ^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.

Table 11.3-4. EMISSION FACTORS FOR HYDROGEN FLUORIDE, TOTAL FLUORIDES, AND HYDROGEN CHLORIDE FROM BRICK MANUFACTURING OPERATIONS^a

Source	HF ^b	EMISSION FACTOR RATING	Total fluorides ^c	EMISSION FACTOR RATING	HCl ^d	EMISSION FACTOR RATING
Sawdust- or natural gas-fired tunnel kiln (SCC 3-05-003-10,-11)						
uncontrolled	0.37 ^e	C	0.59 ^f	E	0.17 ^g	D
with dry scrubber ^h	ND	NA	0.028	C	ND	NA
with medium-efficiency wet scrubber ^j	ND	NA	0.18	C	ND	NA
with high-efficiency packed-bed scrubber ^k	ND	NA	0.0013	C	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	E	ND	NA	ND	NA

^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.

Table 11.3-5. EMISSION FACTORS FOR TOC, METHANE, AND VOC
FROM BRICK MANUFACTURING OPERATIONS^a

Source	TOC ^b	EMISSION FACTOR RATING	Methane	EMISSION FACTOR RATING	VOC ^c	EMISSION FACTOR RATING
Brick dryer ^d (SCC 3-05-003-50)	0.05 ^e	E	0.02 ^f	E	0.03	E
Brick dryer w/supplemental gas burner (SCC 3-05-003-51)	0.14 ^g	E	0.11 ^h	E	0.03	E
Brick kiln ^j (SCC 3-05-003-10,-11,-13)	0.062 ^k	C	0.037 ^m	E	0.024	D
Sawdust-fired kiln and sawdust dryer ⁿ (SCC 3-05-003-61)	0.18	E	ND	NA	0.18	E

^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

EMISSION FACTOR RATING: E

Source	Pollutant		Emission Factor, lb/ton	Ref. No.
	CASRN	Name		
Coal-fired kiln (SCC 3-05-003-13)	75-34-3	1,1-dichloroethane	5.0×10^{-6}	9
	71-55-6	1,1,1-trichloroethane ^{b*}	BDL (1.7×10^{-5})	9
	106-46-7	1,4-dichlorobenzene	3.2×10^{-6}	9
	78-93-3	2-butanone	2.5×10^{-4}	9
	591-78-6	2-hexanone ^b	BDL (9.4×10^{-7})	9
	91-57-6	2-methylnaphthalene	1.7×10^{-6}	9
	95-48-7	2-methylphenol ^b	BDL (2.2×10^{-6})	9
	67-64-1	Acetone*	6.8×10^{-4}	9
	71-43-2	Benzene	2.9×10^{-4}	9
	65-85-0	Benzoic acid	2.5×10^{-4}	9
	117-81-7	Bis(2-ethylhexy)phthalate	7.3×10^{-5}	9
	74-83-9	Bromomethane	2.4×10^{-5}	9
	85-68-7	Butylbenzylphthalate	1.2×10^{-6}	9
	75-15-0	Carbon disulfide	2.3×10^{-6}	9
	56-23-5	Carbon tetrachloride ^b	BDL (1.0×10^{-7})	9
	108-90-7	Chlorobenzene	2.1×10^{-5}	9
	75-00-3	Chloroethane	1.1×10^{-5}	9
	67-66-3	Chloroform ^b	BDL (1.0×10^{-7})	9
	74-87-3	Chloromethane	1.1×10^{-4}	9
	132-64-9	Dibenzofuran ^c	3.6×10^{-7}	9
		Di-n-octylphthalate	1.2×10^{-5}	9
	84-66-2	Diethylphthalate	1.4×10^{-6}	9
	131-11-3	Dimethylphthalate ^b	BDL (7.8×10^{-7})	9
	100-41-4	Ethylbenzene	2.1×10^{-5}	9
	78-59-1	Isophorone	3.0×10^{-5}	9
	1330-20-7	M-/p-xylene	1.3×10^{-4}	9
	75-09-2	Methylene chloride*	8.0×10^{-7}	9
	91-20-3	Naphthalene	6.9×10^{-6}	9
	95-47-6	O-xylene	4.7×10^{-5}	9
	108-95-2	Phenol	3.5×10^{-5}	9
	100-42-5	Styrene ^b	BDL (1.0×10^{-7})	9
	127-18-4	Tetrachloroethane ^b	BDL (1.0×10^{-7})	9
	71-55-6	Trichloroethane ^{b*}	BDL (1.0×10^{-7})	9
	108-88-3	Toluene	2.5×10^{-4}	9
	108-05-4	Vinyl acetate ^b	BDL (1.0×10^{-7})	9
	75-69-4	Trichlorofluoromethane*	1.4×10^{-5}	9

Table 11.3-6 (cont.).

Source	Pollutant		Emission Factor, lb/ton	Ref. No.
	CASRN	Name		
Natural gas-fired kiln (SCC 3-05-003-11)	71-55-6	1,1,1-Trichloroethane*	4.7×10^{-6}	8
	106-46-7	1,4-dichlorobenzene	4.8×10^{-5}	8
	91-57-6	2-methylnaphthalene	5.7×10^{-5}	8
	78-93-3	2-butanone	0.00022	8
	591-78-6	2-Hexanone	8.5×10^{-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	1.8×10^{-5}	8
	75-15-0	Carbon disulfide	4.3×10^{-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	4.4×10^{-5}	8
	1330-20-7	M-/p-Xylene	6.7×10^{-5}	8
	74-88-4	Iodomethane	9.3×10^{-5}	8
	91-20-3	Naphthalene	6.5×10^{-5}	8
	95-47-6	o-Xylene	5.8×10^{-5}	8
	108-95-2	Phenol	8.6×10^{-5}	8
	100-42-5	Styrene	2.0×10^{-5}	8
	127-18-4	Tetrachloroethene	2.8×10^{-6}	8
	108-88-3	Toluene	0.00016	8
Sawdust-fired kiln (SCC 3-05-003-10)	71-55-6	1,1,1-trichloroethane ^{b*}	BDL (3.0×10^{-7})	11
	78-93-3	2-butanone ^b	BDL (6.6×10^{-6})	11
	591-78-6	2-hexanone ^b	BDL (3.0×10^{-7})	11
	95-48-7	2-methylphenol ^b	BDL (2.0×10^{-9})	11
	67-64-1	Acetone*	3.9×10^{-4}	11
	107-13-1	Acrylonitrile ^c	1.5×10^{-5}	11
	71-43-2	Benzene	5.2×10^{-4}	11
	117-81-7	Bis(2-ethylhexy)phthalate	2.9×10^{-5}	11
	74-83-9	Bromomethane	5.0×10^{-5}	11
	75-15-0	Carbon disulfide	1.6×10^{-5}	11
	56-23-5	Carbon tetrachloride ^b	BDL (3.0×10^{-7})	11
	67-66-3	Chloroform ^b	BDL (3.0×10^{-7})	11
	74-87-3	Chloromethane	6.8×10^{-4}	11
	84-74-2	Di-n-butylphthalate ^c	6.1×10^{-6}	11
	132-64-9	Dibenzofuran	1.5×10^{-5}	11

Table 11.3-6 (cont.).

Source	Pollutant		Emission Factor, lb/ton	Ref. No.
	CASRN	Name		
Sawdust-fired kiln (SCC 3-05-003-10)	84-74-2	Dimethylphthalate ^c	1.0×10^{-5}	11
	100-41-4	Ethylbenzene	8.5×10^{-6}	11
	74-88-4	Iodomethane	2.0×10^{-4}	11
	1330-20-7	M-/p-xylene	2.9×10^{-5}	11
	75-09-2	Methylene chloride*	7.5×10^{-6}	11
	91-20-3	Naphthalene ^c	3.4×10^{-4}	11
	95-47-6	O-xylene ^c	3.8×10^{-6}	11
	108-95-2	Phenol	7.2×10^{-5}	11
	100-42-5	Styrene ^b	BDL (4.4×10^{-7})	11
	127-18-4	Tetrachloroethane ^b	BDL (3.0×10^{-7})	11
	108-88-3	Toluene	1.1×10^{-4}	11
	71-55-6	Trichloroethane ^{b*}	BDL (3.0×10^{-7})	11
	75-69-4	Trichlorofluoromethane*	5.8×10^{-6}	11
	108-05-4	Vinyl acetate ^b	BDL (3.0×10^{-7})	11
Sawdust-fired kiln and sawdust dryer ^d (SCC 3-05-003-61)	71-55-6	1,1,1-trichloroethane ^{b*}	BDL (5.2×10^{-7})	11
	78-93-3	2-butanone	2.2×10^{-4}	11
	591-78-6	2-hexanone ^b	BDL (3.8×10^{-7})	11
	95-48-7	2-methylphenol ^b	BDL (2.4×10^{-9})	11
	67-64-1	Acetone*	0.0010	11
	107-13-1	Acrylonitrile	1.9×10^{-5}	11
	71-43-2	Benzene	5.6×10^{-4}	11
	117-81-7	Bis(2-ethylhexy)phthalate	1.4×10^{-4}	11
	74-83-9	Bromomethane	4.4×10^{-5}	11
	75-15-0	Carbon disulfide	1.8×10^{-5}	11
	56-23-5	Carbon tetrachloride ^b	BDL (3.8×10^{-7})	11
	67-66-3	Chloroform ^b	BDL (3.8×10^{-7})	11
	74-87-3	Chloromethane	0.0014	11
	84-74-2	Di-n-butylphthalate	1.6×10^{-5}	11
	132-64-9	Dibenzofuran ^b	BDL (2.4×10^{-9})	11
	131-11-3	Dimethylphthalate ^b	BDL (2.4×10^{-9})	11
	100-41-4	Ethylbenzene	1.0×10^{-5}	11
	74-88-4	Iodomethane	2.4×10^{-4}	11
	1330-20-7	M-/p-xylene	2.9×10^{-5}	11
	75-09-2	Methylene chloride*	6.2×10^{-5}	11
	91-20-3	Naphthalene ^b	BDL (2.4×10^{-9})	11
	95-47-6	O-xylene	7.3×10^{-6}	11
	108-95-2	Phenol	1.0×10^{-4}	11
	100-42-5	Styrene ^b	BDL (4.2×10^{-6})	11
	127-18-4	Tetrachloroethane ^b	BDL (3.8×10^{-7})	11

Table 11.3-6 (cont.).

Source	Pollutant		Emission Factor, lb/ton	Ref. No.
	CASRN	Name		
Sawdust-fired kiln and sawdust dryer ^d (SCC 3-05-003-61)	108-88-3	Toluene	4.3×10^{-4}	11
	71-55-6	Trichloroethane ^{b*}	BDL (3.8×10^{-7})	11
	75-69-4	Trichlorofluoromethane*	1.0×10^{-6}	11
	108-05-4	Vinyl acetate	1.9×10^{-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.

**Table 11.3-7. EMISSION FACTORS FOR METALS EMISSIONS
FROM BRICK MANUFACTURING OPERATIONS^a**

Source	Pollutant	Emission Factor, lb/ton	EMISSION FACTOR RATING	Reference Nos.
Kiln ^b (SCC 3-05-003-10,-11,-13)	Antimony	2.7×10^{-5}	D	8-9,11,25
	Cadmium	1.5×10^{-5}	D	8-9,11,25
	Chromium	5.1×10^{-5}	D	9,11,25
	Cobalt	2.1×10^{-6}	E	25
	Lead	1.5×10^{-4}	D	8-9,11,25
	Nickel	7.2×10^{-5}	D	9,11,25
	Selenium	2.3×10^{-4}	D	8-9,11,25
Coal-fired kiln (SCC 3-05-003-13)	Arsenic	1.3×10^{-4}	E	9
	Beryllium	1.6×10^{-5}	E	9
	Manganese	2.9×10^{-4}	D	8-9,25
	Mercury	9.6×10^{-5}	E	9
	Phosphorus	9.8×10^{-4}	E	9,11
Natural gas-fired kiln (SCC 3-05-003-11)	Arsenic	3.1×10^{-5}	D	8,11,25
	Beryllium	4.2×10^{-7}	D	8,11,25
	Manganese	2.9×10^{-4}	D	8-9,25
	Mercury	7.5×10^{-6}	D	11,25
Sawdust-fired kiln (SCC 3-05-003-10)	Arsenic	3.1×10^{-5}	D	8,11,25
	Beryllium	4.2×10^{-7}	D	8,11,25
	Manganese	0.013 ^c	E	11
	Mercury	7.5×10^{-6}	D	11,25
	Phosphorus	9.8×10^{-4}	E	9,11
Sawdust-fired kiln and sawdust dryer ^d (SCC 3-05-003-61)	Antimony	2.8×10^{-6}	E	11
	Arsenic	2.1×10^{-5}	E	11
	Beryllium	3.1×10^{-7}	E	11
	Cadmium	2.2×10^{-5}	E	11
	Chromium	4.8×10^{-5}	E	11
	Lead	1.2×10^{-4}	E	11
	Manganese	4.8×10^{-4}	E	11
	Mercury	1.1×10^{-5}	E	11
	Nickel	3.4×10^{-5}	E	11
	Phosphorus	5.5×10^{-4}	E	11
	Selenium	4.7×10^{-5}	E	11

^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 coal- and 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 DISTRIBUTION
FOR 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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11.14 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

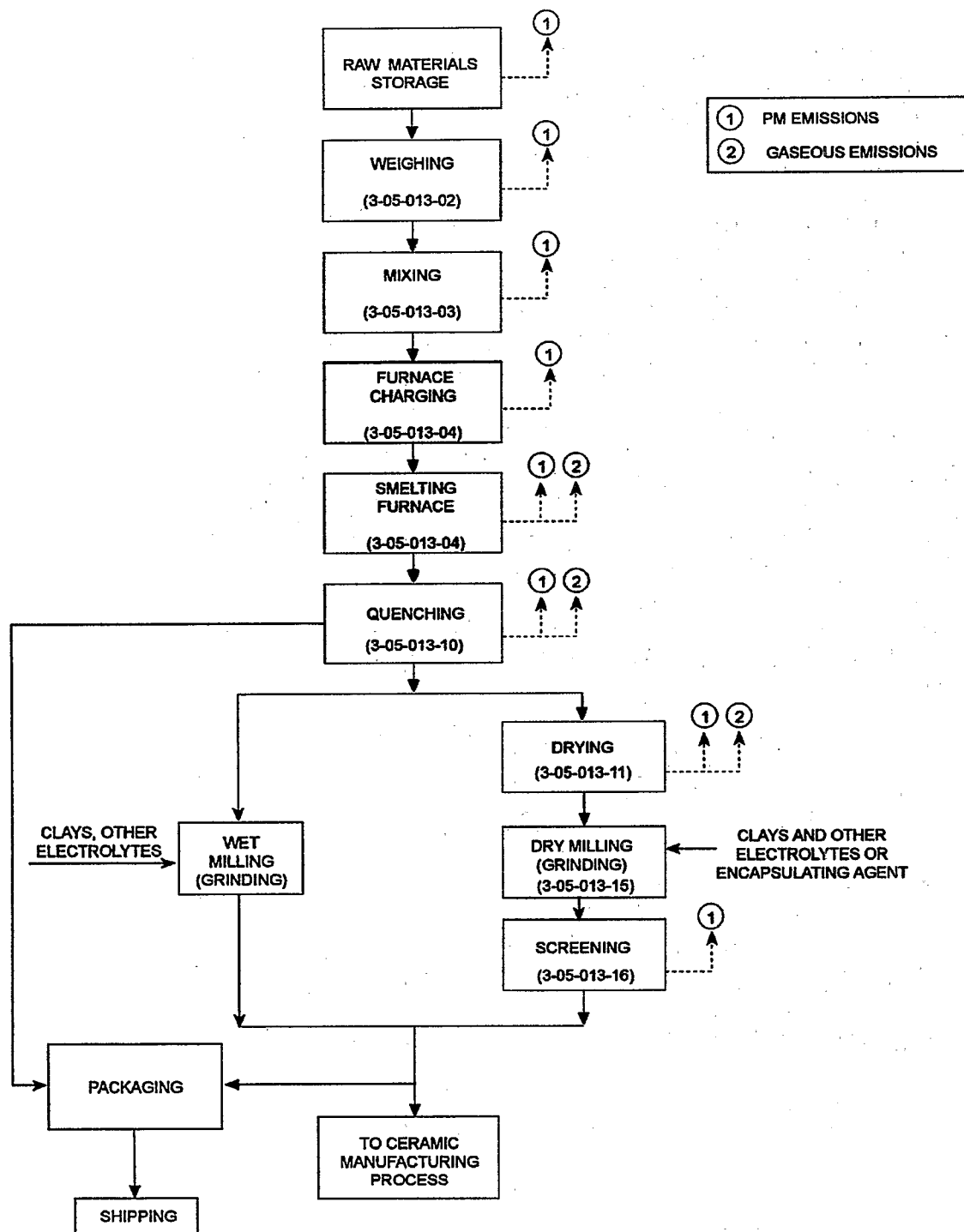


Figure 11.14-1 Process flow diagram for frit manufacturing.
(Source Classification Code in parentheses)

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_x 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 NO_x 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

EMISSION FACTOR RATING: E

Source	Filterable PM ^b	CO	NO _x	CO ₂
Smelting furnace (SCC 3-05-013-05,06)	16 ^c	4.8 ^c	16 ^d	1,300 ^e
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

^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.

^e Reference 7-10.

^f References 7-9. EMISSION FACTOR RATING: D

^g See factor for uncontrolled emissions.

Table 11.14-2. EMISSION FACTORS FOR FRIT MANUFACTURING--
FLUORIDES AND METALS^a

EMISSION FACTOR RATING: E

	Pollutant	Emission factor, lb/ton
Smelting furnace with fabric filter (SCC 3-05-013-05,-06)	fluorides	0.88
	barium	2.8×10^{-5}
	chromium	1.4×10^{-5}
	cobalt	4.3×10^{-6}
	copper	1.9×10^{-5}
	lead	9.6×10^{-6}
	manganese	1.4×10^{-5}
	nickel	1.6×10^{-5}
	zinc	1.2×10^{-4}

^aReference 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

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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.*

11.23 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

Table 11.23-1. KEY FOR SOURCE CLASSIFICATION CODES FOR
TACONITE ORE PROCESSING

Key ^a	Source	SCC
A	Ore storage	3-03-023-05
B	Ore transfer	3-03-023-04
C	Primary crusher	3-03-023-01
D	Primary crusher return conveyor transfer	3-03-023-25
E	Secondary crushing line	3-03-023-27
F	Secondary crusher return conveyor transfer	3-03-023-28
G	Tertiary crushing	3-03-023-02
H	Tertiary crushing line	3-03-023-30
I	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
M	Classification	3-03-023-36
N	Magnetic separation	3-03-023-17
O	Secondary grinding	3-03-023-38
P	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
T	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
X	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. (cont.).

Key ^a	Source	SCC
AN	Vertical shaft, gas-fired, top gas stack, flux pellets	3-03-023-72
AO	Vertical shaft, gas-fired, bottom gas stack, acid pellets	3-03-023-73
AP	Vertical shaft, gas-fired, bottom gas stack, flux pellets	3-03-023-74
AQ	Straight grate, gas-fired, acid pellets	3-03-023-81
AR	Straight grate, gas-fired, flux pellets	3-03-023-82
AS	Straight grate, oil-fired, acid pellets	3-03-023-83
AT	Straight grate, oil-fired, flux pellets	3-03-023-84
AU	Straight grate, coke-fired, acid pellets	3-03-023-85
AV	Straight grate, coke-fired, flux pellets	3-03-023-86
AW	Straight grate, coke- and gas-fired, acid pellets	3-03-023-87
AX	Straight grate, coke- and gas-fired, flux pellets	3-03-023-88
AY	Grate/kiln furnace discharge	3-03-023-50
AZ	Vertical shaft furnace discharge	3-03-023-70
BA	Straight grate furnace discharge	3-03-023-80
BB	Hearth layer screen	3-03-023-93
BC	Pellet cooler	3-03-023-15
BD	Pellet screen	3-03-023-95
BE	Pellet transfer to storage	3-03-023-16
BF	Pellet storage bin loading	3-03-023-96
BG	Secondary storage bin loading	3-03-023-97
BH	Tertiary storage bin loading	3-03-023-98
b	Haul road, rock	3-03-023-21
b	Haul road, taconite	3-03-023-22
b	Nonmagnetic separation	3-03-023-18
b	Tailings basin	3-03-023-40
b	Other, not classified	3-03-023-99
c	Traveling grate feed	3-03-023-09
c	Traveling grate discharge	3-03-023-10
c	Indurating furnace: gas-fired	3-03-023-12
c	Indurating furnace: oil-fired	3-03-023-13
c	Indurating furnace: coal-fired	3-03-023-14
c	Kiln	3-03-023-19
c	Conveyors, transfer, and loading	3-03-023-20

^aRefers to labels in Figure 11.23-1.^bNot shown in Figure 11.23-1.^cInactive code.

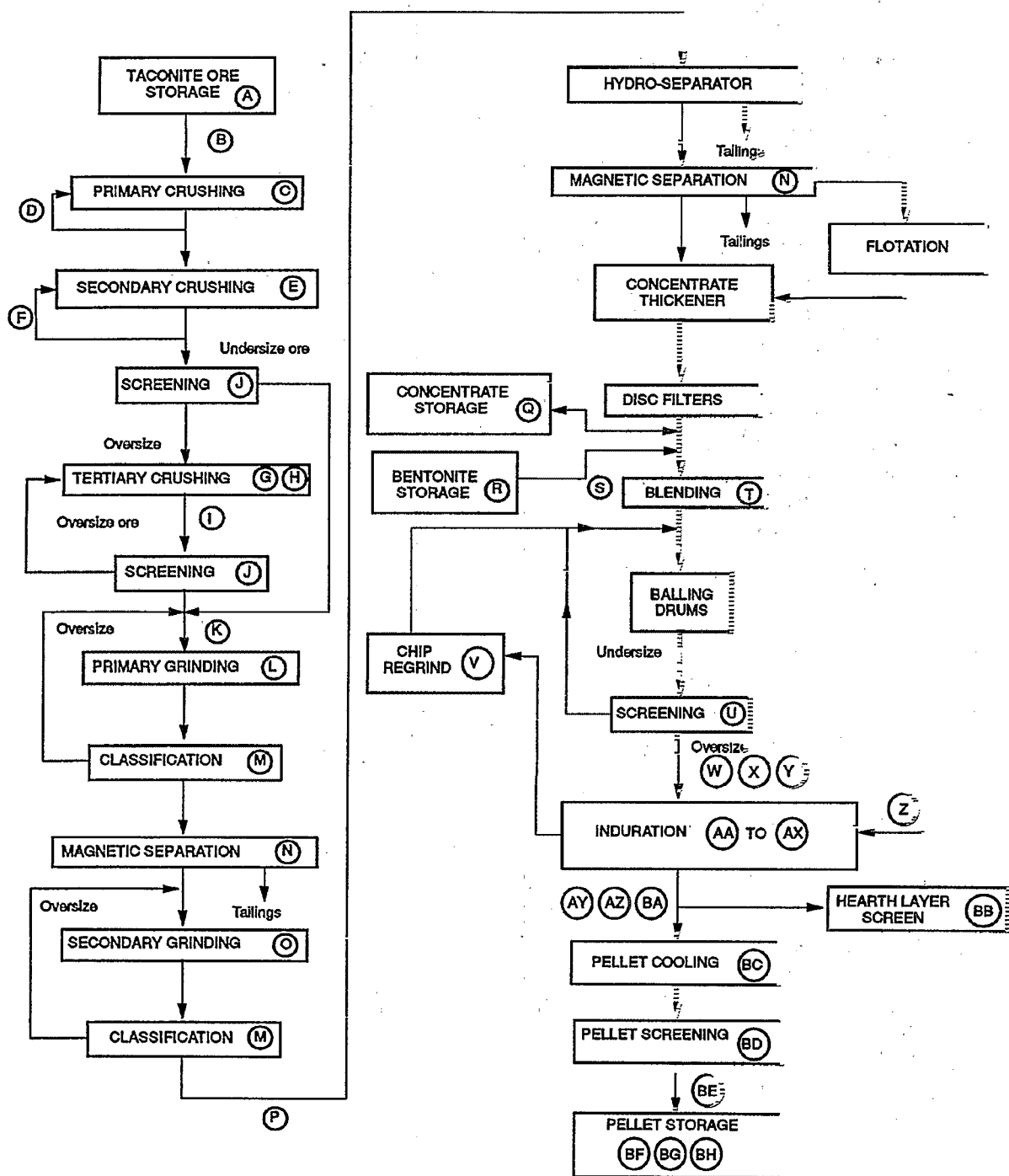


Figure 11.23-1. Process flow diagram for taconite ore processing.
(Refer to Table 11.23-1 for Source Classification Codes)

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, rotocyclone, 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 SO_2 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.

Table 11.23-2. EMISSION FACTORS FOR TACONITE ORE INDURATING FURNACES^a

Source	Filterable ^b				Condensable ^c	EMISSION FACTOR RATING
	PM	EMISSION FACTOR RATING	PM-10	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	E	NA	
Natural gas-fired grate/kiln, with wet scrubber (SCC 3-03-023-51,-52)	0.082 ^j	C	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	E	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	E	ND		0.050 ^t	E
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	E	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 (cont.).

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- ^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.

Table 11.23-3. EMISSION FACTORS FOR TACONITE ORE PROCESSING--
OTHER SOURCES^a

Source	Filterable ^b				Condensable ^c	EMISSION FACTOR RATING
	PM	EMISSION FACTOR RATING	PM-10	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	E	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	E	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	C	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	E	ND		ND	
Grate/kiln feed, with wet scrubber (SCC 3-03-023-49)	6.6 x 10 ^{-5(g)}	E	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	E	ND		0.00012 ^q	E
Straight grate feed (SCC 3-03-023-79)	0.63 ^s	E	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)	10 ^u	E	ND		ND	

Table 11.23-3 (cont.).

Source	Filterable ^b				Condensible ^c	EMISSION FACTOR RATING
	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING		
Pellet screen, with rotoclone (SCC 3-03-023-95)	0.037 ^u	E	ND		ND	
Primary crusher return conveyor transfer, with wet scrubber (SCC 3-03-023-25)	0.00031 ^f	E	ND		ND	
Pellet transfer to storage, with wet scrubber (SCC 3-03-023-16)	0.0036 ^m	E	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	E	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	E	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	E	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	E	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	E	ND		ND	
Secondary storage bin loading, with wet scrubber (SCC 3-03-023-97)	0.00019 ^g	E	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.).

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- ^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.

Table 11.23-4. EMISSION FACTORS FOR TACONITE ORE INDURATING FURNACES--
ACID PELLET PRODUCTION^a

Source	SO ₂ ^b	EMISSION FACTOR RATING	NO _x	EMISSION FACTOR RATING	CO	EMISSION FACTOR RATING	CO ₂ ^c	EMISSION FACTOR RATING
Natural gas-fired grate/kiln (SCC 3-03-023-51)	0.29 ^d	D	1.5 ^e	D	0.014 ^f	D	99 ^g	C
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	E	ND		ND		99 ^g	C
Coal/coke-fired grate/kiln, (SCC 3-03-023-57)	2.3 ^m	E	ND		ND		99 ^g	C
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	E	0.077 ^p	E	94 ^q	C
Gas-fired vertical shaft top gas stack, with wet scrubber (SCC 3-03-023-71)	0.28 ^p	E	j		j		j	
Gas-fired straight grate (SCC 3-03-023-81)	ND		ND		0.039 ^r	E	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

^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 SO₂ factors presented in this table.

^c Mass balance on carbon may yield a more representative emission factor for a specific facility than the CO₂ 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.

^j 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.

**Table 11.23-5. EMISSION FACTORS FOR TACONITE ORE INDURATING FURNACES--
FLUX PELLET PRODUCTION^a**

Source	SO ₂ ^b	EMISSION FACTOR RATING	NO _x	EMISSION FACTOR RATING	CO	EMISSION FACTOR RATING	CO ₂ ^c	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	C
Coal/coke-fired grate/kiln, with wet scrubber (SCC 3-03-023-58)	1.5 ^h	D	ND		ND		130 ^g	C
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	E

^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 SO₂ factors presented in this table.

^c Mass balance on carbon may yield a more representative emission factor for a specific facility than the CO₂ 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.

Table 11.23-6. EMISSION FACTORS FOR TACONITE ORE PROCESSING--
OTHER POLLUTANTS^a

EMISSION FACTOR RATING: E

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

^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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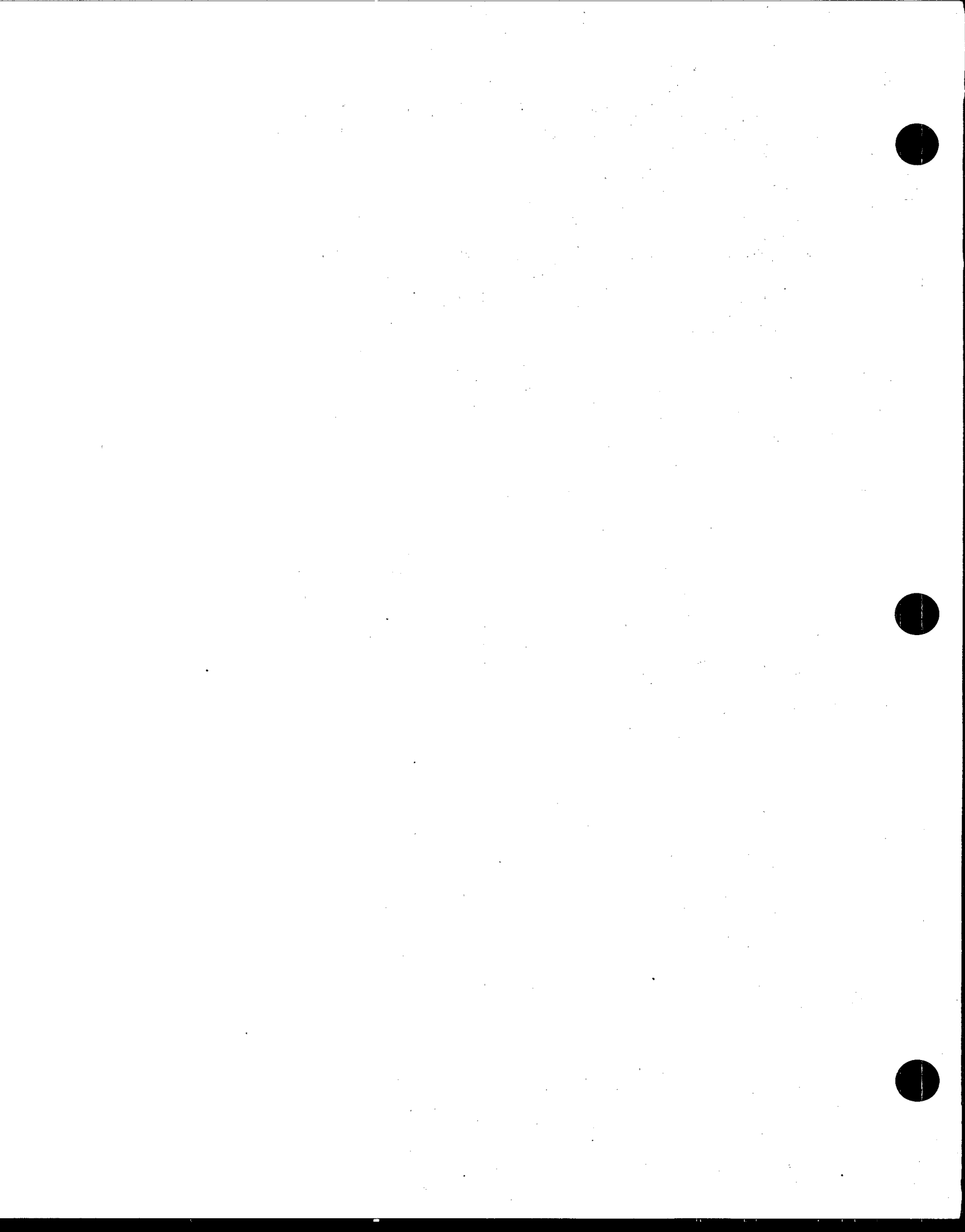
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