11.6 Portland Cement Manufacturing

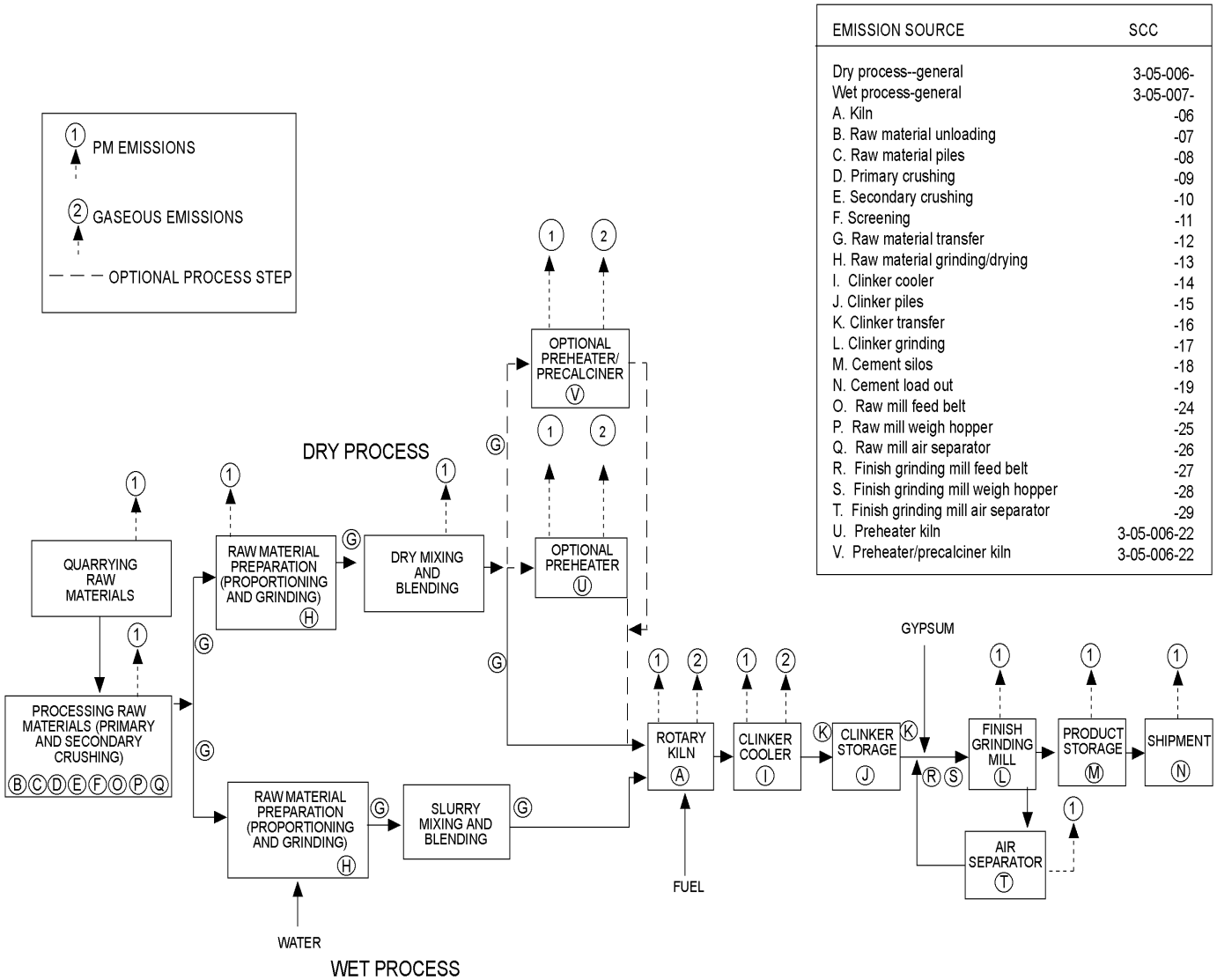
11.6.1 Process Description[1-7]

Portland cement is a fine powder, gray or white in color, that consists of a mixture of hydraulic cement materials comprising primarily calcium silicates, aluminates and aluminoferrites. More than 30 raw materials are known to be used in the manufacture of portland cement, and these materials can be divided into four distinct categories: calcareous, siliceous, argillaceous, and ferrifrous. These materials are chemically combined through pyroprocessing and subjected to subsequent mechanical processing operations to form gray and white portland cement. Gray portland cement is used for structural applications and is the more common type of cement produced. White portland cement has lower iron and manganese contents than gray portland cement and is used primarily for decorative purposes. Portland cement manufacturing plants are part of hydraulic cement manufacturing, which also includes natural, masonry, and pozzolanic cement. The six-digit Source Classification Code (SCC) for portland cement plants with wet process kilns is 3-05-006, and the six-digit SCC for plants with dry process kilns is 3-05-007.

Portland cement accounts for 95 percent of the hydraulic cement production in the United States. The balance of domestic cement production is primarily masonry cement. Both of these materials are produced in portland cement manufacturing plants. A diagram of the process, which encompasses production of both portland and masonry cement, is shown in Figure 11.6-1. As shown in the figure, the process can be divided into the following primary components: raw materials acquisition and handling, kiln feed preparation, pyroprocessing, and finished cement grinding. Each of these process components is described briefly below. The primary focus of this discussion is on pyroprocessing operations, which constitute the core of a portland cement plant.

The initial production step in portland cement manufacturing is raw materials acquisition. Calcium, the element of highest concentration in portland cement, is obtained from a variety of calcareous raw materials, including limestone, chalk, marl, sea shells, aragonite, and an impure limestone known as "natural cement rock". Typically, these raw materials are obtained from open-face quarries, but underground mines or dredging operations are also used. Raw materials vary from facility to facility. Some quarries produce relatively pure limestone that requires the use of additional raw materials to provide the correct chemical blend in the raw mix. In other quarries, all or part of the noncalcarious constituents are found naturally in the limestone. Occasionally, pockets of pyrite, which can significantly increase emissions of sulfur dioxide (SO_2), are found in deposits of limestone, clays, and shales used as raw materials for portland cement. Because a large fraction (approximately one third) of the mass of this primary material is lost as carbon dioxide (CO_2) in the kiln, portland cement plants are located close to a calcareous raw material source whenever possible. Other elements included in the raw mix are silicon, aluminum, and iron. These materials are obtained from ores and minerals such as sand, shale, clay, and iron ore. Again, these materials are most commonly from open-pit quarries or mines, but they may be dredged or excavated from underwater deposits.

Either gypsum or natural anhydrite, both of which are forms of calcium sulfate, is introduced to the process during the finish grinding operations described below. These materials, also excavated from quarries or mines, are generally purchased from an external source, rather than obtained directly from a captive operation by the cement plant. The portland cement manufacturing industry is relying increasingly on replacing virgin materials with waste materials or byproducts from other manufacturing



EMISSION SOURCE	SCC
Dry process--general	3-05-006-
Wet process-general	3-05-007-
A. Kiln	-06
B. Raw material unloading	-07
C. Raw material piles	-08
D. Primary crushing	-09
E. Secondary crushing	-10
F. Screening	-11
G. Raw material transfer	-12
H. Raw material grinding/drying	-13
I. Clinker cooler	-14
J. Clinker piles	-15
K. Clinker transfer	-16
L. Clinker grinding	-17
M. Cement silos	-18
N. Cement load out	-19
O. Raw mill feed belt	-24
P. Raw mill weigh hopper	-25
Q. Raw mill air separator	-26
R. Finish grinding mill feed belt	-27
S. Finish grinding mill weigh hopper	-28
T. Finish grinding mill air separator	-29
U. Preheater kiln	3-05-006-22
V. Preheater/precalciner kiln	3-05-006-22

Figure 11.6-1. Process flow diagram for portland cement manufacturing. (SCC = Source Classification Code.)

operations, to the extent that such replacement can be implemented without adversely affecting plant operations, product quality or the environment. Materials that have been used include fly ash, mill scale, and metal smelting slags.

The second step in portland cement manufacture is preparing the raw mix, or kiln feed, for the pyroprocessing operation. Raw material preparation includes a variety of blending and sizing operations that are designed to provide a feed with appropriate chemical and physical properties. The raw material processing operations differ somewhat for wet and dry processes, as described below.

Cement raw materials are received with an initial moisture content varying from 1 to more than 50 percent. If the facility uses dry process kilns, this moisture is usually reduced to less than 1 percent before or during grinding. Drying alone can be accomplished in impact dryers, drum dryers, paddle-equipped rapid dryers, air separators, or autogenous mills. However, drying can also be accomplished during grinding in ball-and-tube mills or roller mills. While thermal energy for drying can be supplied by exhaust gases from separate, direct-fired coal, oil, or gas burners, the most efficient and widely used source of heat for drying is the hot exit gases from the pyroprocessing system.

Materials transport associated with dry raw milling systems can be accomplished by a variety of mechanisms, including screw conveyors, belt conveyors, drag conveyors, bucket elevators, air slide conveyors, and pneumatic conveying systems. The dry raw mix is pneumatically blended and stored in specially constructed silos until it is fed to the pyroprocessing system.

In the wet process, water is added to the raw mill during the grinding of the raw materials in ball or tube mills, thereby producing a pumpable slurry, or slip, of approximately 65 percent solids. The slurry is agitated, blended, and stored in various kinds and sizes of cylindrical tanks or slurry basins until it is fed to the pyroprocessing system.

The heart of the portland cement manufacturing process is the pyroprocessing system. This system transforms the raw mix into clinkers, which are gray, glass-hard, spherically shaped nodules that range from 0.32 to 5.1 centimeters (cm) (0.125 to 2.0 inches [in.]) in diameter. The chemical reactions and physical processes that constitute the transformation are quite complex, but they can be viewed conceptually as the following sequential events:

1. Evaporation of free water;

2. Evolution of combined water in the argillaceous components;

3. Calcination of the calcium carbonate ($CaCO_3$) to calcium oxide (CaO);

4. Reaction of CaO with silica to form dicalcium silicate;

5. Reaction of CaO with the aluminum and iron-bearing constituents to form the liquid phase;

6. Formation of the clinker nodules;

7. Evaporation of volatile constituents (e. g., sodium, potassium, chlorides, and sulfates); and

8. Reaction of excess CaO with dicalcium silicate to form tricalcium silicate.

This sequence of events may be conveniently divided into four stages, as a function of location and temperature of the materials in the rotary kiln.

1. Evaporation of uncombined water from raw materials, as material temperature increases to 100°C (212°F);

2. Dehydration, as the material temperature increases from 100°C to approximately 430°C (800°F) to form oxides of silicon, aluminum, and iron;

3. Calcination, during which carbon dioxide (CO_2) is evolved, between 900°C (1650°F) and 982°C (1800°F), to form CaO; and

4. Reaction, of the oxides in the burning zone of the rotary kiln, to form cement clinker at temperatures of approximately 1510°C (2750°F).

Rotary kilns are long, cylindrical, slightly inclined furnaces that are lined with refractory to protect the steel shell and retain heat within the kiln. The raw material mix enters the kiln at the elevated end, and the combustion fuels generally are introduced into the lower end of the kiln in a countercurrent manner. The materials are continuously and slowly moved to the lower end by rotation of the kiln. As they move down the kiln, the raw materials are changed to cementitious or hydraulic minerals as a result of the increasing temperature within the kiln. The most commonly used kiln fuels are coal, natural gas, and occasionally oil. The use of supplemental fuels such as waste solvents, scrap rubber, and petroleum coke has expanded in recent years.

Five different processes are used in the portland cement industry to accomplish the pyroprocessing step: the wet process, the dry process (long dry process), the semidry process, the dry process with a preheater, and the dry process with a preheater/precalciner. Each of these processes accomplishes the physical/chemical steps defined above. However, the processes vary with respect to equipment design, method of operation, and fuel consumption. Generally, fuel consumption decreases in the order of the processes listed. The paragraphs below briefly describe the process, starting with the wet process and then noting differences in the other processes.

In the wet process and long dry process, all of the pyroprocessing activity occurs in the rotary kiln. Depending on the process type, kilns have length-to-diameter ratios in the range of 15:1 to 40:1. While some wet process kilns may be as long as 210 m (700 ft), many wet process kilns and all dry process kilns are shorter. Wet process and long dry process pyroprocessing systems consist solely of the simple rotary kiln. Usually, a system of chains is provided at the feed end of the kiln in the drying or preheat zones to improve heat transfer from the hot gases to the solid materials. As the kiln rotates, the chains are raised and exposed to the hot gases. Further kiln rotation causes the hot chains to fall into the cooler materials at the bottom of the kiln, thereby transferring the heat to the load.

Dry process pyroprocessing systems have been improved in thermal efficiency and productive capacity through the addition of one or more cyclone-type preheater vessels in the gas stream exiting the rotary kiln. This system is called the preheater process. The vessels are arranged vertically, in series, and are supported by a structure known as the preheater tower. Hot exhaust gases from the rotary kiln pass countercurrently through the downward-moving raw materials in the preheater vessels. Compared to the simple rotary kiln, the heat transfer rate is significantly increased, the degree of heat utilization is greater, and the process time is markedly reduced by the intimate contact of the solid particles with the hot gases. The improved heat transfer allows the length of the rotary kiln to be reduced. The hot gases from the preheater tower are often used as a source of heat for drying raw materials in the raw mill. Because the catch from the mechanical collectors, fabric filters, and/or

electrostatic precipitators (ESP) that follow the raw mill is returned to the process, these devices are considered to be production machines as well as pollution control devices.

Additional thermal efficiencies and productivity gains have been achieved by diverting some fuel to a calciner vessel at the base of the preheater tower. This system is called the preheater/precalciner process. While a substantial amount of fuel is used in the precalciner, at least 40 percent of the thermal energy is required in the rotary kiln. The amount of fuel that is introduced to the calciner is determined by the availability and source of the oxygen for combustion in the calciner. Calciner systems sometimes use lower-quality fuels (e. g., less-volatile matter) as a means of improving process economics.

Preheater and precalciner kiln systems often have an alkali bypass system between the feed end of the rotary kiln and the preheater tower to remove the undesirable volatile constituents. Otherwise, the volatile constituents condense in the preheater tower and subsequently recirculate to the kiln. Buildup of these condensed materials can restrict process and gas flows. The alkali content of portland cement is often limited by product specifications because excessive alkali metals (i. e., sodium and potassium) can cause deleterious reactions in concrete. In a bypass system, a portion of the kiln exit gas stream is withdrawn and quickly cooled by air or water to condense the volatile constituents to fine particles. The solid particles, containing the undesirable volatile constituents, are removed from the gas stream and thus the process by fabric filters and ESPs.

The semidry process is a variation of the dry process. In the semidry process, the water is added to the dry raw mix in a pelletizer to form moist nodules or pellets. The pellets then are conveyed on a moving grate preheater before being fed to the rotary kiln. The pellets are dried and partially calcined by hot kiln exhaust gases passing through the moving grate.

Regardless of the type of pyroprocess used, the last component of the pyroprocessing system is the clinker cooler. This process step recoups up to 30 percent of the heat input to the kiln system, locks in desirable product qualities by freezing mineralogy, and makes it possible to handle the cooled clinker with conventional conveying equipment. The more common types of clinker coolers are (1) reciprocating grate, (2) planetary, and (3) rotary. In these coolers, the clinker is cooled from about 1100°C to 93°C (2000°F to 200°F) by ambient air that passes through the clinker and into the rotary kiln for use as combustion air. However, in the reciprocating grate cooler, lower clinker discharge temperatures are achieved by passing an additional quantity of air through the clinker. Because this additional air cannot be utilized in the kiln for efficient combustion, it is vented to the atmosphere, used for drying coal or raw materials, or used as a combustion air source for the precalciner.

The final step in portland cement manufacturing involves a sequence of blending and grinding operations that transforms clinker to finished portland cement. Up to 5 percent gypsum or natural anhydrite is added to the clinker during grinding to control the cement setting time, and other specialty chemicals are added as needed to impart specific product properties. This finish milling is accomplished almost exclusively in ball or tube mills. Typically, finishing is conducted in a closed-circuit system, with product sizing by air separation.

11.6.2 Emissions And Controls[1,3-7]

Particulate matter (PM and PM-10), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), and CO_2 are the primary emissions in the manufacture of portland cement. Small quantities of volatile organic compounds (VOC), ammonia (NH_3), chlorine, and hydrogen chloride (HCl), also may be emitted. Emissions may also include residual materials from the fuel and raw materials or products of incomplete combustion that are considered to be hazardous. Because some

facilities burn waste fuels, particularly spent solvents in the kiln, these systems also may emit small quantities of additional hazardous organic pollutants. Also, raw material feeds and fuels typically contain trace amounts of heavy metals that may be emitted as a particulate or vapor.

Sources of PM at cement plants include (1) quarrying and crushing, (2) raw material storage, (3) grinding and blending (in the dry process only), (4) clinker production, (5) finish grinding, and (6) packaging and loading. The largest emission source of PM within cement plants is the pyroprocessing system that includes the kiln and clinker cooler exhaust stacks. Often, dust from the kiln is collected and recycled into the kiln, thereby producing clinker from the dust. However, if the alkali content of the raw materials is too high, some or all of the dust is discarded or leached before being returned to the kiln. In many instances, the maximum allowable cement alkali content of 0.6 percent (calculated as sodium oxide) restricts the amount of dust that can be recycled. Bypass systems sometimes have a separate exhaust stack. Additional sources of PM are raw material storage piles, conveyors, storage silos, and unloading facilities. Emissions from portland cement plants constructed or modified after August 17, 1971 are regulated to limit PM emissions from portland cement kilns to 0.15 kg/Mg (0.30 lb/ton) of feed (dry basis), and to limit PM emissions from clinker coolers to 0.050 kg/Mg (0.10 lb/ton) of feed (dry basis).

Oxides of nitrogen are generated during fuel combustion by oxidation of chemically-bound nitrogen in the fuel and by thermal fixation of nitrogen in the combustion air. As flame temperature increases, the amount of thermally generated NO_x increases. The amount of NO_x generated from fuel increases with the quantity of nitrogen in the fuel. In the cement manufacturing process, NO_x is generated in both the burning zone of the kiln and the burning zone of a precalcining vessel. Fuel use affects the quantity and type of NO_x generated. For example, in the kiln, natural gas combustion with a high flame temperature and low fuel nitrogen generates a larger quantity of NO_x than does oil or coal, which have higher fuel nitrogen but which burn with lower flame temperatures. The opposite may be true in a precalciner. Types of fuels used vary across the industry. Historically, some combination of coal, oil, and natural gas was used, but over the last 15 years, most plants have switched to coal, which generates less NO_x than does oil or gas. However, in recent years a number of plants have switched to systems that burn a combination of coal and waste fuel. The effect of waste fuel use on NO_x emissions is not clearly established.

Sulfur dioxide may be generated both from the sulfur compounds in the raw materials and from sulfur in the fuel. The sulfur content of both raw materials and fuels varies from plant to plant and with geographic location. However, the alkaline nature of the cement provides for direct absorption of SO_2 into the product, thereby mitigating the quantity of SO_2 emissions in the exhaust stream. Depending on the process and the source of the sulfur, SO_2 absorption ranges from about 70 percent to more than 95 percent.

The CO_2 emissions from portland cement manufacturing are generated by two mechanisms. As with most high-temperature, energy-intensive industrial processes, combusting fuels to generate process energy releases substantial quantities of CO_2. Substantial quantities of CO_2 also are generated through calcining of limestone or other calcareous material. This calcining process thermally decomposes $CaCO_3$ to CaO and CO_2. Typically, portland cement contains the equivalent of about 63.5 percent CaO. Consequently, about 1.135 units of $CaCO_3$ are required to produce 1 unit of cement, and the amount of CO_2 released in the calcining process is about 500 kilograms (kg) per Mg of portland cement produced (1,000 pounds [lb] per ton of cement). Total CO_2 emissions from the pyroprocess depend on energy consumption and generally fall in the range of 0.85 to 1.35 Mg of CO_2 per Mg of clinker.

In addition to CO_2 emissions, fuel combustion at portland cement plants can emit a wide range of pollutants in smaller quantities. If the combustion reactions do not reach completion, CO and volatile organic pollutants, typically measured as total organic compounds (TOC), VOC, or organic condensable particulate, can be emitted. Incomplete combustion also can lead to emissions of specific hazardous organic air pollutants, although these pollutants are generally emitted at substantially lower levels than CO or TOC.

Emissions of metal compounds from portland cement kilns can be grouped into three general classes: volatile metals, including mercury (Hg) and thallium (Tl); semivolatile metals, including antimony (Sb), cadmium (Cd), lead (Pb), selenium (Se), zinc (Zn), potassium (K), and sodium (Na); and refractory or nonvolatile metals, including barium (Ba), chromium (Cr), arsenic (As), nickel (Ni), vanadium (V), manganese (Mn), copper (Cu), and silver (Ag). Although the partitioning of these metal groups is affected by kiln operating conditions, the refractory metals tend to concentrate in the clinker, while the volatile and semivolatile metals tend to be discharged through the primary exhaust stack and the bypass stack, respectively.

Fugitive dust sources in the industry include quarrying and mining operations, vehicle traffic during mineral extraction and at the manufacturing site, raw materials storage piles, and clinker storage piles. The measures used to control emissions from these fugitive dust sources are comparable to those used throughout the mineral products industries. Vehicle traffic controls include paving and road wetting. Controls that are applied to other open dust sources include water sprays with and without surfactants, chemical dust suppressants, wind screens, and process modifications to reduce drop heights or enclose storage operations. Additional information on these control measures can be found in Chapter 13 of AP-42, "Miscellaneous Sources".

Process fugitive emission sources include materials handling and transfer, raw milling operations in dry process facilities, and finish milling operations. Typically, emissions from these processes are captured by a ventilation system and collected in fabric filters. Some facilities use an air pollution control system comprising one or more mechanical collectors with a fabric filter in series. Because the dust from these units is returned to the process, they are considered to be process units as well as air pollution control devices. The industry uses shaker, reverse air, and pulse jet filters as well as some cartridge units, but most newer facilities use pulse jet filters. For process fugitive operations, the different systems are reported to achieve typical outlet PM loadings of 45 milligrams per cubic meter (mg/m^3) (0.02 grains per actual cubic foot [gr/acf]).

In the pyroprocessing units, PM emissions are controlled by fabric filters (reverse air, pulse jet, or pulse plenum) and electrostatic precipitators (ESP). Typical control measures for the kiln exhaust are reverse air fabric filters with an air-to-cloth ratio of 0.41:1 $m^3/min/m^2$ (1.5:1 $acfm/ft^2$) and ESP with a net surface collection area of 1,140 to 1,620 $m^2/1{,}000\ m^3$ (350 to 500 $ft^2/1{,}000\ ft^3$). These systems are reported to achieve outlet PM loadings of 45 mg/m^3 (0.02 gr/acf). Clinker cooler systems are controlled most frequently with pulse jet or pulse plenum fabric filters. A few gravel bed filters also have been used to control clinker cooler emissions. Typical outlet PM loadings are identical to those reported for kilns.

Cement kiln systems have highly alkaline internal environments that can absorb up to 95 percent of potential SO_2 emissions. However, in systems that have sulfide sulfur (pyrites) in the kiln feed, the sulfur absorption rate may be as low as 70 percent without unique design considerations or changes in raw materials. The cement kiln system itself has been determined to provide substantial SO_2 control. Fabric filters on cement kilns are also reported to absorb SO_2. Generally, substantial control is not achieved. An absorbing reagent (e. g., CaO) must be present in the filter cake for SO_2 capture to occur. Without the presence of water, which is undesirable in the operation of a fabric

filter, $CaCO_3$ is not an absorbing reagent. It has been observed that as much as 50 percent of the SO_2 can be removed from the pyroprocessing system exhaust gases when this gas stream is used in a raw mill for heat recovery and drying. In this case, moisture and calcium carbonate are simultaneously present for sufficient time to accomplish the chemical reaction with SO_2.

Tables 11.6-1 and 11.6-2 present emission factors for PM emissions from portland cement manufacturing kilns and clinker coolers. Tables 11.6-3 and 11.6-4 present emission factors for PM emissions from raw material and product processing and handling. Particle size distributions for emissions from wet process and dry process kilns are presented in Table 11.6-5, and Table 11.6-6 presents the particle size distributions for emissions from clinker coolers. Emission factors for SO_2, NO_x, CO, CO_2, and TOC emissions from portland cement kilns are summarized in Tables 11.6-7 and 11.6-8. Table 11.6-9 summarizes emission factors for other pollutant emissions from portland cement kilns.

Because of differences in the sulfur content of the raw material and fuel and in process operations, a mass balance for sulfur may yield a more representative emission factor for a specific facility than the SO_2 emission factors presented in Tables 11.6-7 and 11.6-8. In addition, CO_2 emission factors estimated using a mass balance on carbon may be more representative for a specific facility than the CO_2 emission factors presented in Tables 11.6-7 and 11.6-8.

Table 11.6-1 (Metric Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING KILNS AND CLINKER COOLERS[a]

Process	Filterable[b]				Condensable[c]			
	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Wet process kiln (SCC 3-05-007-06)	65[d]	D	16[e]	D	ND		ND	
Wet process kiln with ESP (SCC 3-05-007-06)	0.38[f]	C	0.33[g]	D	0.076[h]	D	ND	
Wet process kiln with fabric filter (SCC 3-05-007-06)	0.23[j]	E	ND		0.10[j]	E	ND	
Wet process kiln with cooling tower, multiclone, and ESP (SCC 3-05-007-06)	0.10[k]	E	ND		0.14[k]	E	ND	
Dry process kiln with ESP (SCC 3-05-006-06)	0.50[m]	D	ND		0.19[m]	D	ND	
Dry process kiln with fabric filter (SCC 3-05-006-06)	0.10[n]	D	0.084[p]	D	0.45[n]	D	ND	
Preheater kiln (SCC 3-05-006-22)	130[q]	D	ND		ND		ND	
Preheater kiln with ESP (SCC 3-05-006-22)	0.13[r]	D	ND		ND		ND	
Preheater kiln with fabric filter (SCC 3-05-006-22)	0.13[s]	C	ND		0.017[t]	D	ND	
Preheater/precalciner kiln with ESP (SCC 3-05-006-23)	0.024[u]	D	ND		ND		ND	
Preheater/precalciner process kiln with fabric filter (SCC 3-05-006-23)	0.10[v]	D	ND		ND		ND	
Preheater/precalciner process kiln with PM controls (SCC 3-05-006-23)	ND		ND		0.078[w]	D	ND	

Table 11.6-1 (cont.).

Process	Filterable[b]				Condensable[c]			
	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Clinker cooler with ESP (SCC 3-05-006-14)	0.048[x]	D	ND		0.0038[x]	D	ND	
Clinker cooker with fabric filter (SCC 3-05-006-14)	0.068[y]	D	ND		0.0084[z]	D	ND	
Clinker cooler with gravel bed filter (SCC 3-05-006-14)	0.11[aa]	D	0.084[bb]	D	0.0045[cc]	D	ND	

[a] Factors represent uncontrolled emissions unless, otherwise noted. Factors are kg/Mg of clinker produced, unless noted. SCC = Source Classification Code. ND = no data. ESP = electrostatic precipitator.
[b] Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.
[c] Condensable PM is that collected in the impinger portion of a PM sampling train.
[d] References 20,26.
[e] References 3,20,26.
[f] References 8-9,18,20,25-26,32,34-36,41-44,60,64.
[g] References 3,8-9,18,20,25-26,32,34-36,41-44,60,64.
[h] References 8-9,20,64.
[j] Reference 14.
[k] Reference 21.
[m] References 19,21.
[n] Reference 23.
[p] References 3,23.
[q] Reference 17.
[r] Reference 31.
[s] References 17,47-50,61.
[t] Reference 51.
[u] Reference 37.
[v] References 30,33,51,56-59,63
[w] References 30,33,37,51,59.
[x] Reference 8.
[y] References 9,12,27,30,33.
[z] References 9,12,30.
[aa] References 22,29,31
[bb] References 3,22,29,31
[cc] References 22,29

Table 11.6-2 (English Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING KILNS AND CLINKER COOLERS[a]

Process	Filterable[b]				Condensable[c]			
	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Wet process kiln (SCC 3-05-007-06)	130[d]	D	31[e]	D	ND		ND	
Wet process kiln with ESP (SCC 3-05-007-06)	0.77[f]	C	0.65[g]	D	0.15[h]	D	ND	
Wet process kiln with fabric filter (SCC 3-05-007-06)	0.46[j]	E	ND		0.20[j]	E	ND	
Wet process kiln with cooling tower, multiclone, and ESP (SCC 3-05-007-06)	0.20[k]	E	ND		0.29[k]	E	ND	
Dry process kiln with ESP (SCC 3-05-006-06)	1.0[m]	D	ND		0.38[m]	D	ND	
Dry process kiln with fabric filter (SCC 3-05-006-06)	0.20[n]	D	0.17[p]	D	0.89[n]	D	ND	
Preheater kiln (SCC 3-05-006-22)	250[q]	D	ND		ND		ND	
Preheater kiln with ESP (SCC 3-05-006-22)	0.26[r]	D	ND		ND		ND	
Preheater kiln with fabric filter (SCC 3-05-006-22)	0.25[s]	C	ND		0.033[t]	D	ND	
Preheater/precalciner kiln with ESP (SCC 3-05-006-23)	0.048[u]	D	ND		ND		ND	
Preheater/precalciner process kiln with fabric filter (SCC 3-05-006-23)	0.21[v]	D	ND		ND		ND	
Preheater/precalciner process kiln with PM controls (SCC 3-05-006-23)	ND		ND		0.16[w]	D	ND	

Table 11.6-2 (cont.).

Process	Filterable[b]				Condensable[c]			
	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING	Inorganic	EMISSION FACTOR RATING	Organic	EMISSION FACTOR RATING
Clinker cooler with ESP (SCC 3-05-006-14)	0.096[x]	D	ND		0.0075[x]	D	ND	
Clinker cooker with fabric filter (SCC 3-05-006-14)	0.13[y]	D	ND		0.017[z]	D	ND	
Clinker cooler with gravel bed filter (SCC 3-05-006-14)	0.21[aa]	D	0.16[bb]	D	0.0090[cc]	D	ND	

[a] Factors represent uncontrolled emissions unless otherwise noted. Factors are lb/ton of clinker produced unless noted. SCC = Source Classification Code. ND = no data. ESP = electrostatic precipitator.
[b] Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.
[c] Condensable PM is that collected in the impinger portion of a PM sampling train.
[d] References 20,26.
[e] References 3,20,26.
[f] References 8-9,18,20,25-26,32,34-36,41-44,60,64.
[g] References 3,8-9,18,20,25-26,32,34-36,41-44,60,64.
[h] References 8-9,20,64.
[j] Reference 14.
[k] Reference 21.
[m] References 19,21.
[n] Reference 23.
[p] References 3,23.
[q] Reference 17.
[r] Reference 31.
[s] References 17,47-50,61.
[t] Reference 51.
[u] Reference 37.
[v] References 30,33,51,56-59,63
[w] References 30,33,37,51,59.
[x] Reference 8.
[y] References 9,12,27,30,33.
[z] References 9,12,30.
[aa] References 22,29,31
[bb] References 3,22,29,31
[cc] References 22,29

Table 11.6-3 (Metric Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING RAW MATERIAL AND PRODUCT PROCESSING AND HANDLING[a]

Process	Filterable[b]			
	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING
Raw mill with fabric filter (SCC 3-05-006-13)	0.0062[c]	D	ND	
Raw mill feed belt with fabric filter (SCC 3-05-006-24)	0.0016[d]	E	ND	
Raw mill weigh hopper with fabric filter (SCC 3-05-006-25)	0.010[e]	E	ND	
Raw mill air separator with fabric filter (SCC 3-05-006-26)	0.016[e]	E	ND	
Finish grinding mill with fabric filter (SCC 3-05-006-17, 3-05-007-17)	0.0042[f]	D	ND	
Finish grinding mill feed belt with fabric filter (SCC 3-05-006-27, 3-05-007-27)	0.0012[d]	E	ND	
Finish grinding mill weigh hopper with fabric filter (SCC 3-05-006-28, 3-05-007-28)	0.0047[e]	E	ND	
Finish grinding mill air separator with fabric filter (SCC 3-05-006-29, 3-05-007-29)	0.014[g]	D	ND	
Primary limestone crushing with fabric filter (SCC 3-05-006-09)[h]	0.00050	E	ND	
Primary limestone screening with fabric filter (SCC 3-05-006-11)[h]	0.00011	E	ND	
Limestone transfer with fabric filter (SCC 3-05-006-12)[h]	1.5×10^{-5}	E	ND	
Secondary limestone screening and crushing with fabric filter (SCC 3-05-006-10 + -11, 3-05-007-10 + -11)[h]	0.00016	E	ND	

[a] Factors represent uncontrolled emissions, unless otherwise noted. Factors are kg/Mg of material process, unless noted. SCC = Source Classification Code. ND = no data.

4b[b] Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.

[c] References 15,56-57.

[d] Reference 57.

[e] Reference 15.

[f] References 10,12,15,56-57.

[g] References 10,15.

[h] Reference 16. Alternatively, emission factors from Section 11.19.2, "Crushed Stone Processing", can be used for similar processes and equipment.

Table 11.6-4 (English Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING RAW MATERIAL AND PRODUCT PROCESSING AND HANDLING[a]

Process	Filterable[b]			
	PM	EMISSION FACTOR RATING	PM-10	EMISSION FACTOR RATING
Raw mill with fabric filter (SCC 3-05-006-13)	0.012[c]	D	ND	
Raw mill feed belt with fabric filter (SCC 3-05-006-24)	0.0031[d]	E	ND	
Raw mill weigh hopper with fabric filter (SCC 3-05-006-25)	0.019[e]	E	ND	
Raw mill air separator with fabric filter (SCC 3-05-006-26)	0.032[e]	E	ND	
Finish grinding mill with fabric filter (SCC 3-05-006-17, 3-05-007-17)	0.0080[f]	E	ND	
Finish grinding mill feed belt with fabric filter (SCC 3-05-006-27, 3-05-007-27)	0.0024[d]	E	ND	
Finish grinding mill weigh hopper with fabric filter (SCC 3-05-006-28, 3-05-007-28)	0.0094[e]	E	ND	
Finish grinding mill air separator with fabric filter (SCC 3-05-006-29, 3-05-007-29)	0.028[g]	D	ND	
Primary limestone crushing with fabric filter (SCC 3-05-006-09)[h]	0.0010	E	ND	
Primary limestone screening with fabric filter (SCC 3-05-006-11)[h]	0.00022	E	ND	
Limestone transfer with fabric filter (SCC 3-05-006-12)[h]	2.9×10^{-5}	E	ND	
Secondary limestone screening and crushing with fabric filter (SCC 3-05-006-10 + -11, 3-05-007-10 + -11)[h]	0.00031	E	ND	

[a] Factors represent uncontrolled emissions, unless otherwise noted. Factors are lb/ton of material processed, unless noted. SCC = Source Classification Code. ND = no data.
[b] Filterable PM is that collected on or before the filter of an EPA Method 5 (or equivalent) sampling train.
[c] References 15,56-57.
[d] Reference 57.
[e] Reference 15.
[f] References 10,12,15,56-57.
[g] References 10,15.
[h] Reference 16. Alternatively, emission factors from the Section 11.19.2, "Crushed Stone Processing", can be used for similar processes and equipment.

Table 11.6-5. SUMMARY OF AVERAGE PARTICLE SIZE DISTRIBUTION FOR PORTLAND CEMENT KILNS[a]

Particle Size, µm	Cumulative Mass Percent Equal To Or Less Than Stated Size			
	Uncontrolled		Controlled	
	Wet process (SCC 3-05-007-06)	Dry process (SCC 3-05-006-06)	Wet process With ESP (SCC 3-05-007-06)	Dry process With FF (SCC 3-05-006-06)
2.5	7	18	64	45
5.0	20	ND	83	77
10.0	24	42	85	84
15.0	35	44	91	89
20.0	57	ND	98	100

[a] Reference 3. SCC = Source Classification Code. ND = no data.

Table 11.6-6. SUMMARY OF AVERAGE PARTICLE SIZE DISTRIBUTION FOR PORTLAND CEMENT CLINKER COOLERS[a]

Particle Size, µm	Cumulative Mass Percent Equal To Or Less Than Stated Size	
	Uncontrolled (SCC 3-05-006-14, 3-05-007-14)	With Gravel Bed Filter (SCC 3-05-006-14, 3-05-007-14)
2.5	0.54	40
5.0	1.5	64
10.0	8.6	76
15.0	21	84
20.0	34	89

[a] Reference 3. SCC = Source Classification Code.

Table 11.6-7 (Metric Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING[a]

Process	SO_2[b]	EMISSION FACTOR RATING	NO_x	EMISSION FACTOR RATING	CO	EMISSION FACTOR RATING	CO_2[c]	EMISSION FACTOR RATING	TOC	EMISSION FACTOR RATING
Wet process kiln (SCC 3-05-007-06)	4.1[d]	C	3.7[e]	D	0.060[f]	D	1,100[g]	D	0.014[f]	D
Long dry process kiln (SCC 3-05-006-06)	4.9[h]	D	3.0[j]	D	0.11[k]	E	900[m]	D	0.014[n]	E
Preheater process kiln (SCC 3-05-006-22)	0.27[p]	D	2.4[q]	D	0.49[r]	D	900[s]	C	0.090[t]	D
Preheater/precalciner kiln (SCC 3-05-006-23)	0.54[u]	D	2.1[v]	D	1.8[w]	D	900[x]	E	0.059[y]	D
Preheater/precalciner kiln with spray tower (SCC 3-05-006-23)	0.50[z]	E	ND		ND		ND		ND	

[a] Factors represent uncontrolled emissions unless otherwise noted. Factors are kg/Mg of clinker produced, unless noted. SCC = Source Classification Code. ND = no data.
[b] Mass balance on sulfur may yield a more representative emission factor for a specific facility than the SO_2 emission factors presented in this table.
[c] Mass balance on carbon may yield a more representative emission factor for a specific facility than the CO_2 emission factors presented in this table.
[d] References 20,25-26,32,34-36,41-44,60,64.
[e] References 26,34-36,43,64.
[f] Reference 64.
[g] References 25-26,32,34-36,44,60,64.
[h] References 11,19,39,40.
[j] References 11,38-40,65.
[k] References 39,65.
[m] References 11,21,23,65.
[n] References 40,65. TOC as measured by Method 25A or equivalent.
[p] References 47-50.
[q] References 48-50.
[r] Reference 49.
[s] References 24,31,47-50,61.

Table 11.6-7 (cont.).

[t] Reference 49; total organic compounds as measured by Method 25A or equivalent.
[u] References 28,30,33,37,53,56-59.
[v] References 28,30,33,37,45,56-59.
[w] References 28,30,37,56-58,63.
[x] References 24,31,47-50,61. Based on test data for preheater kilns; should be considered an upper limit.
[y] References 30,33,56,63; total organic compounds as measured using Method 25A or equivalent.
[z] Reference 54.

Table 11.6-8 (English Units). EMISSION FACTORS FOR PORTLAND CEMENT MANUFACTURING[a]

Process	SO_2[b]	EMISSION FACTOR RATING	NO_x	EMISSION FACTOR RATING	CO	EMISSION FACTOR RATING	CO_2[c]	EMISSION FACTOR RATING	TOC	EMISSION FACTOR RATING
Wet process kiln (SCC 3-05-007-06)	8.2[d]	C	7.4[e]	D	0.12[f]	D	2,100[g]	D	0.028[f]	D
Long dry process kiln (SCC 3-05-006-06)	10[h]	D	6.0[j]	D	0.21[k]	E	1,800[m]	D	0.028[n]	E
Preheater process kiln (SCC 3-05-006-22)	0.55[p]	D	4.8[q]	D	0.98[r]	D	1,800[s]	C	0.18[t]	D
Preheater/precalciner kiln (SCC 3-05-006-23)	1.1[u]	D	4.2[v]	D	3.7[w]	D	1,800[x]	E	0.12[y]	D
Preheater/precalciner kiln with spray tower (SCC 3-05-006-23)	1.0[z]	E	ND		ND		ND		ND	

[a] Factors represent uncontrolled emissions unless otherwise noted. Factors are lb/ton of clinker produced, unless noted. SCC = Source Classification Code. ND = no data.
[b] Mass balance on sulfur may yield a more representative emission factor for a specific facility than the SO_2 emission factors presented in this table.
[c] Mass balance on carbon may yield a more representative emission factor for a specific facility than the CO_2 emission factors presented in this table.
[d] References 20,25-26,32,34-36,41-44,60,64.
[e] References 26,34-36,43,64.
[f] Reference 64.
[g] References 25-26,32,34-36,44,60,64.
[h] References 11,19,39-40.
[j] References 11,38-40,65.
[k] References 39,65.
[m] References 11,21,23,65.
[n] References 40,65. TOC as measured by Method 25A or equivalent.
[p] References 47-50.
[q] References 48-50.
[r] Reference 49.
[s] References 24,31,47-50,61.
[t] Reference 49; total organic compounds as measured by Method 25A or equivalent.

Table 11.6-8 (cont.).

[u] References 28,30,33,37,53,56-59.
[v] References 28,30,33,37,45, and 56 to 59.
[w] References 28,30,37,56-58,63.
[x] References 24,31,47-50,61. Based on test data for preheater kilns; should be considered an upper limit.
[y] References 30,33,56,63; total organic compounds as measured using Method 25A or equivalent.
[z] Reference 54.

Table 11.6-9 (Metric And English Units). SUMMARY OF NONCRITERIA POLLUTANT EMISSION FACTORS FOR PORTLAND CEMENT KILNS[a]
(SCC 3-05-006-06, 3-05-007-06, 3-05-006-22, 3-05-006-23)

Pollutant Name	Type Of Control	Average Emission Factor		EMISSION FACTOR RATING	References
		kg/Mg	lb/ton		
Inorganic Pollutants					
Silver (Ag)	FF	3.1×10^{-7}	6.1×10^{-7}	D	63
Aluminum (Al)	ESP	0.0065	0.013	E	65
Arsenic (As)	ESP	6.5×10^{-6}	1.3×10^{-5}	E	65
Arsenic (As)	FF	6.0×10^{-6}	1.2×10^{-5}	D	63
Barium (Ba)	ESP	0.00018	0.00035	D	64
Barium (Ba)	FF	0.00023	0.00046	D	63
Beryllium (Be)	FF	3.3×10^{-7}	6.6×10^{-7}	D	63
Calcium (Ca)	ESP	0.12	0.24	E	65
Cadmium (Cd)	ESP	4.2×10^{-6}	8.3×10^{-6}	D	64
Cadmium (Cd)	FF	1.1×10^{-6}	2.2×10^{-6}	D	63
Chloride (Cl)	ESP	0.34	0.68	E	25,42-44
Chloride (Cl)	FF	0.0011	0.0021	D	63
Chromium (Cr)	ESP	3.9×10^{-6}	7.7×10^{-6}	E	64
Chromium (Cr)	FF	7.0×10^{-5}	0.00014	D	63
Copper (Cu)	FF	0.0026	0.0053	E	62
Fluoride (F)	ESP	0.00045	0.00090	E	43
Iron (Fe)	ESP	0.0085	0.017	E	65
Hydrogen chloride (HCl)	ESP	0.025	0.049	E	41,65
Hydrogen chloride (HCl)	FF	0.073	0.14	D	59,63
Mercury (Hg)	ESP	0.00011	0.00022	D	64
Mercury (Hg)	FF	1.2×10^{-5}	2.4×10^{-5}	D	11,63
Potassium (K)	ESP	0.0090	0.018	D	25,42-43
Manganese (Mn)	ESP	0.00043	0.00086	E	65
Ammonia (NH_3)	FF	0.0051	0.010	E	59
Ammonium (NH_4)	ESP	0.054	0.11	D	25,42-44
Nitrate (NO_3)	ESP	0.0023	0.0046	E	43
Sodium (Na)	ESP	0.020	0.038	D	25,42-44
Lead (Pb)	ESP	0.00036	0.00071	D	64
Lead (Pb)	FF	3.8×10^{-5}	7.5×10^{-5}	D	63
Sulfur trioxide (SO_3)	ESP	0.042	0.086	E	25
Sulfur trioxide (SO_3)	FF	0.0073	0.014	D	24,30,50
Sulfate (SO_4)	ESP	0.10	0.20	D	25,42-44
Sulfate (SO_4)	FF	0.0036	0.0072	D	30,33,52

Table 11.6-9 (cont.).

Pollutant Name		Type Of Control	Average Emission Factor		EMISSION FACTOR RATING	References
			kg/Mg	lb/ton		
	Selenium (Se)	ESP	7.5×10^{-5}	0.00015	E	65
	Selenium (Se)	FF	0.00010	0.00020	E	62
	Thallium (Th)	FF	2.7×10^{-6}	5.4×10^{-6}	D	63
	Titanium (Ti)	ESP	0.00019	0.00037	E	65
	Zinc (Zn)	ESP	0.00027	0.00054	D	64
	Zinc (Zn)	FF	0.00017	0.00034	D	63
Organic Pollutants						
CASRN[b]	Name					
35822-46-9	1,2,3,4,6,7,8 HpCDD	FF	1.1×10^{-10}	2.2×10^{-10}	E	62
	C3 benzenes	ESP	1.3×10^{-6}	2.6×10^{-6}	E	65
	C4 benzenes	ESP	3.0×10^{-6}	6.0×10^{-6}	E	65
	C6 benzenes	ESP	4.6×10^{-7}	9.2×10^{-7}	E	65
208-96-8	acenaphthylene	FF	5.9×10^{-5}	0.00012	E	62
67-64-1	acetone	ESP	0.00019	0.00037	D	64
100-52-7	benzaldehyde	ESP	1.2×10^{-5}	2.4×10^{-5}	E	65
71-43-2	benzene	ESP	0.0016	0.0031	D	64
71-43-2	benzene	FF	0.0080	0.016	E	62
	benzo(a)anthracene	FF	2.1×10^{-8}	4.3×10^{-8}	E	62
50-32-8	benzo(a)pyrene	FF	6.5×10^{-8}	1.3×10^{-7}	E	62
205-99-2	benzo(b)fluoranthene	FF	2.8×10^{-7}	5.6×10^{-7}	E	62
191-24-2	benzo(g,h,i)perylene	FF	3.9×10^{-8}	7.8×10^{-8}	E	62
207-08-9	benzo(k)fluoranthene	FF	7.7×10^{-8}	1.5×10^{-7}	E	62
65-85-0	benzoic acid	ESP	0.0018	0.0035	D	64
95-52-4	biphenyl	ESP	3.1×10^{-6}	6.1×10^{-6}	E	65
117-81-7	bis(2-ethylhexyl)phthalate	ESP	4.8×10^{-5}	9.5×10^{-5}	D	64
74-83-9	bromomethane	ESP	2.2×10^{-5}	4.3×10^{-5}	E	64
75-15-0	carbon disulfide	ESP	5.5×10^{-5}	0.00011	D	64
108-90-7	chlorobenzene	ESP	8.0×10^{-6}	1.6×10^{-5}	D	64
74-87-3	chloromethane	ESP	0.00019	0.00038	E	64
218-01-9	chrysene	FF	8.1×10^{-8}	1.6×10^{-7}	E	62
84-74-2	di-n-butylphthalate	ESP	2.1×10^{-5}	4.1×10^{-5}	D	64
53-70-3	dibenz(a,h)anthracene	FF	3.1×10^{-7}	6.3×10^{-7}	E	62
101-41-4	ethylbenzene	ESP	9.5×10^{-6}	1.9×10^{-5}	D	64
206-44-0	fluoranthene	FF	4.4×10^{-6}	8.8×10^{-6}	E	62
86-73-7	fluorene	FF	9.4×10^{-6}	1.9×10^{-5}	E	62
50-00-0	formaldehyde	FF	0.00023	0.00046	E	62

Table 11.6-9 (cont.).

Pollutant		Type Of Control	Average Emission Factor		EMISSION FACTOR RATING	References
CASRN[b]	Name		kg/Mg	lb/ton		
	freon 113	ESP	2.5×10^{-5}	5.0×10^{-5}	E	65
193-39-5	indeno(1,2,3-cd)pyrene	FF	4.3×10^{-8}	8.7×10^{-8}	E	62
78-93-3	methyl ethyl ketone	ESP	1.5×10^{-5}	3.0×10^{-5}	E	64-65
75-09-2	methylene chloride	ESP	0.00025	0.00049	E	65
	methylnaphthalene	ESP	2.1×10^{-6}	4.2×10^{-6}	E	65
91-20-3	naphthalene	FF	0.00085	0.0017	E	62
91-20-3	naphthalene	ESP	0.00011	0.00022	D	64
85-01-8	phenanthrene	FF	0.00020	0.00039	E	62
108-95-2	phenol	ESP	5.5×10^{-5}	0.00011	D	64
129-00-0	pyrene	FF	2.2×10^{-6}	4.4×10^{-6}	E	62
100-42-5	styrene	ESP	7.5×10^{-7}	1.5×10^{-6}	E	65
108-88-3	toluene	ESP	0.00010	0.00019	D	64
	total HpCDD	FF	2.0×10^{-10}	3.9×10^{-10}	E	62
3268-87-9	total OCDD	FF	1.0×10^{-9}	2.0×10^{-9}	E	62
	total PCDD	FF	1.4×10^{-9}	2.7×10^{-9}	E	62
132-64-9	total PCDF	FF	1.4×10^{-10}	2.9×10^{-10}	E	62
132-64-9	total TCDF	FF	1.4×10^{-10}	2.9×10^{-10}	E	62
1330-20-7	xylenes	ESP	6.5×10^{-5}	0.00013	D	64

[a] Factors are kg/Mg and lb/ton of clinker produced. SCC = Source Classification Code. ESP = electrostatic precipitator. FF = fabric filter.
[b] Chemical Abstract Service Registry Number (organic compounds only).

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