AP-42 Section 11.6
Reference 5
Report Sect.
Reference

**ASH GROVE CEMENT COMPA**

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**WALTER L. GREER**
VICE PRESIDENT-PRODUCTION AND ENVIRONMENT

September 30, 1993

Mr. Ronald E. Myers
Emission Factors and Methodologies Section
Emission Inventory Branch
U. S. Environmental Protection Agency
Research Triangle Park, NC 27711

Dear Mr. Myers:

Transmitted herewith is a copy of the AP-42 draft materials that you so kindly sent for comment last month. I have provided handwritten comments within Section 2.0, Industry Description . Due to the press of time, I did not repeat the comments in the subsequent sections of the draft material relating to the process description.

Every time I get involved with AP-42, I get disturbed about the age of some of the references on which the AP-42 emission factors are based. Simply put, thirty year old tests on thirty year old dust collectors are not likely to be representative of current practice. This dated information causes problems for regulators and the regulated community. The following is a current example from Ash Grove's experience. One of our plants is relocating a finish mill dust collector discharge duct from inside to outside the mill building. This change requires a permit modification. The permit writer is insisting on using the emission factor from Table 8.6-1 [Finish grinding mill with fabric filter (3-05-006-17)] despite the "D" rating and the fact that the resulting apparent grain loading in the exhaust air is greater than 0.06 gr/acfm. I don't think that there is any dispute that modern dust collectors perform at 0.02 gr/acfm or better. I suspect that other AP-42 emission factors are similarly in error. I regret that I don't have the time or resources to examine each of the factors for reasonableness.

I will admit that the current industry should have generated more data on its emissions over the past thirty years. It is my understanding, however, that the EPA has rejected some data that is clearly more representative of industry practice because certain criteria were not met. I submit that current data that perhaps lacks some QA/QC controls is better than data from obsolete plants that have been closed. I think that EPA and its

contractors are capable of making the required subjective judgements. If the example cited above is representative of the AP-42 emission factors, best engineering judgement can provide more accurate and useful emission factors.

It appears that only one of the more than thirty recently completed Boiler and Industrial Furnace Certification of Compliance Test Burns has been used in developing emission factors. These tests are the most current available and certainly should have met all the required QA/QC standards. I don't understand these omissions.

With regard to $SO_2$ emission factors, I can only reiterate what the cement industry has tried to tell the EPA for years. There is no way to neatly pigeonhole $SO_2$ or $NO_x$ emissions by kiln type. There are too many factors other than the process design that affect $SO_2$ and $NO_x$ emissions. The industry has repeatedly asked that ranges of emissions be used in AP-42 to reflect reality and to clarify for regulators that there is variability in emissions of these gaseous constituents of concern. I have had several calls from Ashok Damle as he tries to make sense of cement industry $NO_x$ emissions data for the ACT document. A recognition of the true emissions profile of the industry in AP-42 is the only way that I know to eliminate this perpetual dilemma. By way of illustration, I am including herewith a copy of graphs of recent $SO_2$, $NO_x$ and CO emissions data from three of Ash Grove's kilns that are operating normally and producing a quality product. Obviously there are long term, average emission rates that can serve for purposes such as PSD determinations. Short term emission rate limitations to account from normal kiln operation are another matter entirely. Square pegs don't often fit in round holes.

It is perhaps long past time that the EPA and the cement industry sit down and decide the information that is required for AP-42 and try to develop that information as expeditiously and as cost effectively as possible. Ash Grove is certainly willing to participate in such an effort through the PCA.

I can only speculate about the causes of the apparent inconsistencies in $CO_2$ data. During compliance tests, $CO_2$ data are taken primarily for purposes of estimating the molecular weight of the exhaust gas. An Orsat or other relatively crude device is used for snapshot measurements. I don't recall ever seeing $CO_2$ emissions quantified over a long period. The amount of kiln dust generated by a kiln system and the degree of calcination of that dust could have a significant effect on the amount of $CO_2$ generated per ton of clinker. I suspect that engineering calculations and material balances may result in more accurate $CO_2$ emission factors

than currently available data. My calculations suggest that there is only about a 10% swing in $CO_2$ emissions between the most efficient to the least efficient kiln system. The amount of CKD generated will mask some of this difference.

I also suspect that the conversion factors from raw material to clinker stated in your letter may have been low. The theoretical factor is about 1.56. Dust losses can increase this value substantially. Dust losses are not necessarily process dependent. I have operated wet kilns with a conversion factor of 1.85. Each plant will have a specific factor and it will be most difficult to generalize a factor by process.

I'm not sure that emission factors for different types of fossil fuel is a practical matter of great concern although some generalized guidance statements could be developed for AP-42. The issue of concern, however, is waste-derived fuels. There is a substantial data base that exists for some classes of waste-derived fuel. I suspect the shortage of data exists for conventional kilns, although I know some data exists. I am concerned that the absence of these data in AP-42 will be troublesome in the long run.

As a final comment, I had trouble using the references for Section 8.6 to evaluate subjectively the emission factors. I am sure that the titles are listed correctly, but these stack test reports have notoriously bad titles. For example, reference 23 relates to a plant in Kansas, but seems to imply that the plant might have been in Houston. Reference 28 might be taken as testing on a Lehigh plant that does not exist in Montgomery, Alabama. A more careful description of the actual plant would be helpful.

I'm sorry that I have not been able to be more specific in my comments. It does appear, however, that better lines of communication are now open between the EPA and the cement industry. With that positive note, I look forward to additional cooperation so that the next version of AP-42 will be better yet.

If you have any questions, please give me a call.

WLG:dkw
Enclosure

cc: ROB CROLIUS, APCA (w/encl.)
MALLORY MAY, PSM (w/encl.)

DRAFT
1982/3612
7/30/93

# EMISSION FACTOR DOCUMENTATION FOR AP-42 SECTION 8.6
Portland Cement Manufacturing

## 1.0 INTRODUCTION

The document "Compilation of Air Pollutant Emissions Factors" (AP-42) has been published by the U. S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. AP-42 is routinely updated by EPA to respond to new emission factor needs of EPA, State and local air pollution control programs, and industry.

An emission factor relates the quantity (weight) of pollutants emitted to a unit of activity of the source. The uses for the emission factors reported in AP-42 include:

1. Estimates of areawide emissions;
2. Estimates of emissions for a specific facility; and
3. Evaluation of emissions relative to ambient air quality.

The purpose of this report is to provide background information from test reports and other information to support the revision of AP-42 Section 8.6, Portland Cement Manufacturing.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the portland cement industry. It includes a characterization of the industry, an overview of the different process types, a description of emissions, and a description of the technology used to control emissions resulting from portland cement production. Section 3 is a review of emission data collection and analysis procedures. It describes the literature search, the screening of emission data reports, and the quality rating system for both emission data and emission factors. Section 4 details revisions to the existing AP-42 section narrative and pollutant emission factor development. It includes the review of specific data sets and the results of data analysis. Section 5 presents AP-42 Section 8.6.

For analytical convenience and by convention, the analytical results from standard cement testing are reported as the oxides. The hydraulic compounds are minerals — silicates & aluminates

calcium silicates

## 2.0 INDUSTRY DESCRIPTION[1]

Portland cement is a fine powder, gray or white in color, that consists of a mixture of hydraulic cement materials comprising primarily metallic oxides. 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 ferrif~~o~~erous. These materials are chemically combined via 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 included under Standard Industrial Code (SIC) Code 3241, hydraulic cement manufacturing, which also includes natural, masonry, and pozzolan~~/~~ic 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.

## 2.1 CHARACTERIZATION OF THE INDUSTRY[1-3]

As of December 1990, there were 112 operating portland cement plants in the United States, with 109 of these plants producing gray cement and the other 3 producing white cement. These 112 plants operated 213 kilns with a total annual clinker capacity of 73.7 x $10^6$ Mg (81 x $10^6$ tons). The kiln population included 80 wet process kilns and 133 dry process kilns. Both the number of facilities and the industry capacity declined in 1990; two plants with a total annual clinker capacity of 492 x $10^3$ megagrams (Mg) (541 x $10^3$ tons) were retired during the year. This decline continues a trend in the industry, which has shown a reduction in clinker capacity in 8 of the last 11 years. The other major trend in the industry is the increased use of waste fuels. In 1989, 33 plants in the United States and Canada reported using waste fuels; the number increased to 55 plants in 1990.

The portland cement manufacturing industry is dispersed geographically throughout the United States, with 36 States having at least one plant. Table 2-1 shows the total number of operating plants and kilns and the total clinker capacity for each State and EPA Region.

TABLE 2-1. SUMMARY OF PORTLAND CEMENT PLANT CAPACITY INFORMATION[2]

| Location | Number of plants, kilns | Capacity, $10^3$ Mg/yr ($10^3$ tons/yr) |
|---|---|---|
| Region I | 1 (1) | 414 (455) |
| Connecticut | 0 | 0 (0) |
| Maine | 1 (1) | 414 (455) |
| Massachusetts | 0 | 0 (0) |
| New Hampshire | 0 | 0 (0) |
| Rhode Island | 0 | 0 (0) |
| Vermont | 0 | 0 (0) |
| Region II | 4 (5) | 2,815 (3,097) |
| New Jersey | 0 | 0 (0) |
| New York | 4 (5) | 2,815 (3,097) |
| Puerto Rico | NA | NA |
| Virgin Islands | NA | NA |
| Region III | 16 (39) | 9,492 (10,442) |
| Delaware | 0 | 0 (0) |
| District of Columbia | 0 | 0 (0) |
| Maryland | 3 (7) | 1,691 (1,860) |
| Pennsylvania | 11 (24) | 6,039 (6,643) |
| Virginia | 1 (5) | 1,015 (1,117) |
| West Virginia | 1 (3) | 747 (822) |
| Region IV |  | 12,599 (13,858) |
| Alabama | 5 (6) | 3,873 (4,260) |
| Florida | 6 (8) | 3,057 (3,363) |
| Georgia | 2 (4) | 1,253 (1,378) |
| Kentucky | 1 (1) | 658 (724) |
| Mississippi | 1 (1) | 458 (504) |
| North Carolina | 0 | 0 (0) |
| South Carolina | 3 (7) | 2,345 (2,579) |
| Tennessee | 2 (3) | 955 (1,050) |
| Region V | 17 (30) | 10,924 (12,016) |
| Illinois | 4 (8) | 2,350 (2,585) |
| Indiana | 4 (8) | 2,573 (2,830) |
| Michigan | 5 (9) | 4,453 (4,898) |
| Minnesota | 0 | 0 (0) |
| Ohio | 4 (5) | 1,548 (1,703) |
| Wisconsin | 0 | 0 (0) |
| Region VI | 18 (34) | 11,165 (12,282) |
| Arkansas | 2 (5) | 1,195 (1,314) |
| Louisiana | 0 | 0 (0) |
| New Mexico | 1 (2) | 449 (494) |
| Oklahoma | 3 (7) | 1,715 (1,887) |
| Texas | 12 (20) | 7,806 (8,587) |

TABLE 2-1. (continued)

| Location | Number of plants, kilns | Capacity, $10^3$ Mg/yr ($10^3$ tons/yr) |
|---|---|---|
| Region VII | 14 (27) | 9,393 (10,332) |
| Iowa | 4 (7) | 2,551 (2,806) |
| Kansas | 4 (11) | 1,716 (1,888) |
| Missouri | 5 (7) | 4,252 (4,677) |
| Nebraska | 1 (2) | 874 (961) |
| Region VIII | 9 (14) | 4,137 (4,551) |
| Colorado | 3 (5) | 1,640 (1,804) |
| Montana | 2 (2) | 538 (592) |
| North Dakota | 0 | 0 (0) |
| South Dakota | 1 (3) | 696 (766) |
| Utah | 2 (3) | 844 (928) |
| Wyoming | 1 (1) | 419 (461) |
| Region IX | 16 (30) | 11,672 (12,840) |
| Arizona | 2 (7) | 1,609 (1,770) |
| California | 12 (20) | 9,447 (10,392) |
| Hawaii | 1 (1) | 239 (263) |
| Nevada | 1 (2) | 377 (415) |
| American Samoa | NA | |
| Virgin Islands | NA | |
| Region X | 4 (4) | 1,057 (1,163) |
| Alaska | 1 (0)[a] | 0 (0) |
| Idaho | 1 (2) | 191 (210) |
| Oregon | 1 (1) | 436 (480) |
| Washington | 1 (1) | 430 (473) |

[a] Grinding plant only.

NA = Data not available.

## 2.2 PROCESS DESCRIPTION[1-3]

Portland cement, which consists of a mixture of the hydraulic cement minerals, calcium silicates, aluminates and aluminoferrites) and calcium sulfate~~s~~, ~~and aluminum and iron compounds,~~ accounts for 95 percent of the hydraulic cement production in the United States. The balance of domestic cement production comprises 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 2-1. 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 focus of the 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. More than 30 raw materials are known to be used to manufacture portland cement. 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. Because a large fraction (approximately one third) of the mass of this primary material is converted to carbon dioxide ($CO_2$) in the kiln, portland cement plants are located in close proximity to a raw material source whenever possible. Other metallic elements ~~materials~~ included in the raw feed 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 extracted via open-pit quarries or mines, but they may be dredged or excavated from underwater deposits.

Either gypsum or natural anhydrite ~~anhydride~~, both of which are forms of calcium sulfate, is introduced to the process during the finish grinding operations described below. These materials are also excavated from quarries or mines. However, they are generally purchased from an external source, rather than obtained directly from a captive operation by the cement plant.

One current trend in the industry is to replace virgin materials as described above with waste materials or byproducts from other manufacturing operations, to the extent that such replacement can the purpose of this symbol should be defined somewhere

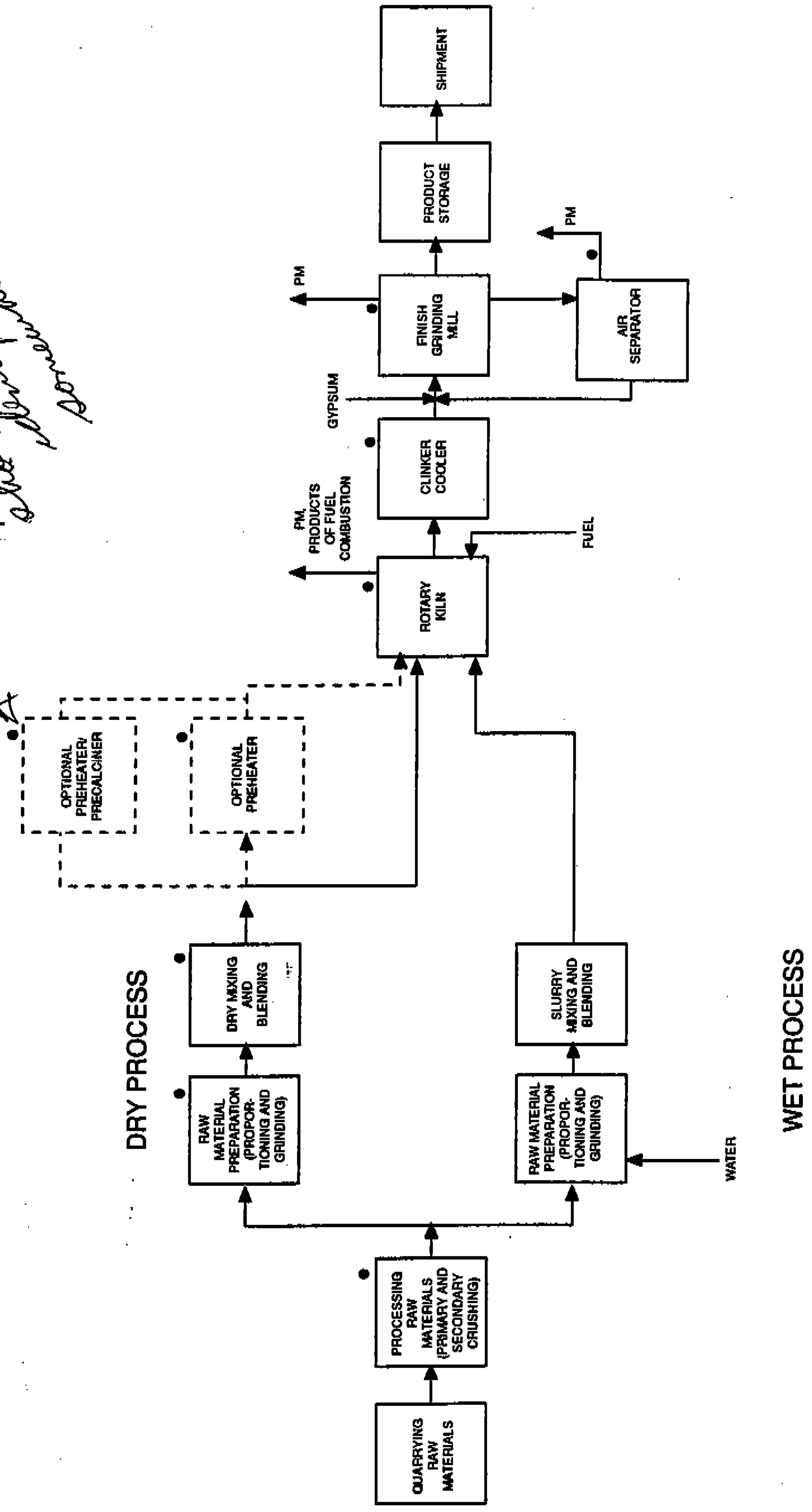


Figure 2-1. Process flow diagram for portland cement manufacturing.

be implemented without adversely affecting plant operations or product quality. 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 ~~feed~~ 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 in the paragraphs 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 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 slip or slurry 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.

?. four

This sequence of events may be conveniently divided into five 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).

where is it?

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, as shown in Figure 2-2. 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 metal oxides by the direct heat exchange. The most commonly used kiln fuels are coal, natural gas, and occasionally oil. Many cement plants currently burn coal, but use of supplemental fuels such as waste solvents, chipped 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 above. 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 ~~35~~: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 after the rotary kiln. This system is called the ~~dry~~ 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 with the simple rotary kiln, the heat transfer rate is significantly increased, the degree of heat utilization is more complete, and the process time is markedly reduced owing to 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's) 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. ~~These~~ this system~~s~~ ~~are~~ is called ~~rotary~~ the preheater/precalciner process~~es~~. 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 ~~a~~ [illegible] 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. 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, which are removed from the gas stream by fabric filters and ESP's, are then returned to the process.

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 ~~to~~ on a moving grate preheater before being fed to the rotary kiln. The pellets are dried and partially calcined ~~in~~ on the moving grate through which hot kiln exhaust gases pass.

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 180°C (2000°F to ~~350~~ 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 ~~airstreams~~ 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 ~~anhydride~~ 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 via air ~~aspiration.~~ separation.

## 2.3 EMISSIONS[1,3,4]

Particulate matter (PM and PM-10), nitrogen oxides ($NO_x$), sulfur dioxide ($SO_2$), carbon monoxide (CO), and $CO_2$ carbon dioxide are the primary emissions in the manufacture of portland cement. Small quantities of volatile organic compounds (VOC's) and ammonia ($NH_3$) also may be emitted. Emissions may also include residual materials from the fuel and raw materials that are considered to be hazardous. Because some facilities burn waste fuels, particularly spent solvents, in both the kiln and precalciner, these systems also ~~may~~ emit ~~hazardous~~ negligible quantities of organic pollutants. Also, raw ~~mineral~~ material feeds and fuels typically contain trace amounts of heavy metals that may be emitted as constituents in the PM. However, their quantities are likely to be negligible. and no substantive data are available on metals emissions. also.

(wrong! There are numerous B/F metals emissions tests

If you are going to mention these constituents, HCl & $Cl_2$ might should be mentioned as well.

This is more editorial than factual. See the B/F test results

Something should be said the PM front half only.
emissions are measured in the 5
cement industry as ~~That~~

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~~s~~ of PM within cement plants ~~are~~ is the ~~three units that make up~~ the pyroprocessing system ~~: the feed system, the fuel firing system, and the clinker cooling and handling system~~ that includes the kiln and clinker cooler exhaust stacks. ~~Typically~~ Often, dust from the~~se~~ ~~operations~~ kiln is collected and recycled into the kiln ~~burning zone~~, thereby producing clinker from the dust. However, if the alkali content of the raw materials is

The B/F rules prohibit hazardous waste-derived fuels in the precalciner.

~~that~~ Bypass systems sometimes have a separate exhaust stack.

too high, some or all of the dust is discarded or leached before returning it 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. Additional sources of PM are raw material storage piles, conveyors, storage silos, and loading/unloading facilities.

If the zones of the kiln are to be used in the text, they should be defined/described.

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, and 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 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, 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 burn with lower flame temperatures. 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 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.

The $CO_2$ emissions from portland cement manufacturing are generated by two mechanisms. As with most high-temperature, energy-intensive industrial processes, combustion of fossil 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 ~~about~~ the equivalent of 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).

The actual CaO content of cement ~~is~~ ranges from about 60% to 65%. See earlier comment about analytical convention a ~~Some~~ of the calcium reported as CaO comes from the gypsum which is not a source of $CO_2$. Check your figures. They are, however, appropriately correct.

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, which are typically measured as total hydrocarbons (THC) or volatile organic compounds (VOC's), can be emitted. When waste fuels are used, incomplete combustion can lead to emissions of specific hazardous organic air pollutants, although these pollutants are generally emitted at substantially lower levels than CO or THC. ← Another editorial comment perhaps. Coal & oil combustion also generates PIC's

## 2.4 CONTROL TECHNOLOGY[1,3]

~~Open~~ Fugitive dust sources in the industry include quarrying and mining operations, vehicular 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. Vehicular 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 11 of AP-42.

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 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]).

Don't see many mechanical collectors anymore, just fabric filters

In the pyroprocessing units, PM emissions are controlled by fabric filters (reverse air, pulse jet, or pulse plenum) and ESP's. Typical control measures for the kiln exhaust are reverse air fabric filters with an air-to-cloth ratio of 0.41:1 meter per minute (m/min) (1.5:1 $acfm/ft^2$) and ESP's with a net SCA of 1,140 to 1,620 square meters per thousand $m^3$ ($m^2/1,000\ m^3$) (350 to 500 square feet per thousand $ft^3$ [$ft^2/1,000\ ft^3$]). These systems are reported to achieve outlet PM loadings of 45 $mg/m^3$

Shouldn't this be a volumetric unit

(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 on clinker coolers. 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 50 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 $SO_2$.

## REFERENCES FOR SECTION 2

1. W. L. Greer, et al., "Portland Cement", Air Pollution Engineering Manual, A. J. Buonicore and W. T. Davis (eds.), Von Nostrand Reinhold, New York 1992.

2. U. S. and Canadian Portland Cement Industry Plant Information Summary, December 31, 1990, Portland Cement Association, Washington, DC, August 1991.

3. "Chapter 8.6, Portland Cement Manufacturing, Compilation of Air Pollutant Emission Factors, AP-42, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1991.

4. Written communication from Robert W. Crolius, Portland Cement Association, to Ron Myers, U. S. Environmental Protection Agency, Research Triangle Park, NC. March 11, 1992.

# 3.0 GENERAL DATA REVIEW AND ANALYSIS

## 3.1 LITERATURE SEARCH AND SCREENING[1]

Data for this investigation were obtained from a number of sources within the Office of Air Quality Planning and Standards (OAQPS) and from outside organizations. The AP-42 Background Files located in the Emission Inventory Branch (EIB) were reviewed for information on the industry, processes, and emissions. The Crosswalk/Air Toxic Emission Factor Data Base Management System (XATEF) and VOC/PM Speciation Data Base Management System (SPECIATE) data bases were searched by SCC code to identify potential pollutants emitted and emission factors for those pollutants. A general search of the Air CHIEF CD-ROM also was conducted to supplement the information from these two data bases. Information on the industry, including number of plants, plant location, and annual production capacities was obtained from industry reports recently prepared by the Portland Cement Association (PCA).

A number of sources of information were investigated specifically for emission test reports and data. A search of the Test Method Storage and Retrieval (TSAR) data base was conducted to identify test reports for sources within the portland cement industry. Copies of these test reports were obtained from the files of the Emission Measurement Branch (EMB). The EPA library was searched for additional test reports. A list of plants that have been tested within the past 5 years was compiled from the AIRS data base. Using this information, State and Regional offices were contacted about the availability of test reports. However, the information obtained from these offices was limited. Publications lists from the Office of Research and Development (ORD) and Control Technology Center (CTC) were also searched for reports on emissions from the portland cement industry. In addition, the PCA was contacted for assistance in obtaining information about the industry and emissions, and information supplied by PCA for the 1989 AP-42 revision was received.

To screen out unusable test reports, documents, and information from which emission factors could not be developed, the following general criteria were used:

1. Emission data must be from a primary reference:
    a. Source testing must be from a referenced study that does not reiterate information from previous studies.

   b. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was contained in the previous document. If the exact source of the data could not be determined, the document was eliminated.

2. The referenced study must contain test results based on more than one test run.
3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions (e.g., one-page reports were generally rejected).

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria.

## 3.2 EMISSION DATA QUALITY RATING SYSTEM

As part of the analysis of the emission data, the quantity and quality of the information contained in the final set of reference documents were evaluated. The following data were excluded from consideration:

1. Test series averages reported in units that cannot be converted to the selected reporting units;

2. Test series representing incompatible test methods (i.e., comparison of EPA Method 5 front half with EPA Method 5 front and back halves);

3. Test series of controlled emissions for which the control device is not specified;

4. Test series in which the source process is not clearly identified and described; and

5. Test series in which it is not clear whether the emissions were measured before or after the control device.

Test data sets that were not excluded were assigned a quality rating. The rating system used was that specified by EIB for preparing AP-42 sections. The data were rated as follows:

A--Multiple tests that were performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily conform to the methodology specified in EPA reference test methods, although these methods were used as a guide for the methodology actually used.

B--Tests that were performed by a generally sound methodology, but lack enough detail for adequate validation.

C--Tests that were based on an untested or new methodology or that lacked a significant amount of background data.

D--Tests that were based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following criteria were used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurred, an evaluation was made of the extent to which such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data are documented in the report, and any variations in the sampling and process operation are noted. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and are given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those (if any) specified by EPA to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the

ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

## 3.3 EMISSION FACTOR QUALITY RATING SYSTEM

The quality of the emission factors developed from analysis of the test data was rated utilizing the following general criteria:

A--Excellent: Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough so that variability within the source category population may be minimized.

B--Above average: Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. The source category is specific enough so that variability within the source category population may be minimized.

C--Average: Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. In addition, the source category is specific enough so that variability within the source category population may be minimized.

D--Below average: The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are noted in the emission factor table.

E--Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always noted.

The use of these criteria is somewhat subjective and depends to an extent upon the individual reviewer. Details of the rating of each candidate emission factor are provided in Chapter 4 of this report.

## REFERENCES FOR SECTION 3

1. Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections (Draft), Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 6, 1992.

# 4.0 AP-42 SECTION DEVELOPMENT

## 4.1 REVISIONS TO SECTION NARRATIVE

The draft AP-42 section described in this report replaces Section 8.6, Portland Cement Manufacturing, in the current version of AP-42. Although this section was revised most recently in 1991, the process description and emissions and controls discussion had major flaws. Specifically, components of the process other than pyroprocessing were not described (although emission factors were presented for other operations), the different types of dry processes (long dry kiln, dry kiln with preheater, and dry kiln with preheater/precalciner) were not clearly delineated, and the use of waste fuels by the industry was not discussed. Information contained in the recently updated Air Pollution Engineering manual and materials supplied by the Portland Cement Association on industry characteristics and $CO_2$ emissions were used to update the discussion.

## 4.2 POLLUTANT EMISSION FACTOR DEVELOPMENT

A total of 79 documents were reviewed in the process of developing emission factors for this revision to the AP-42 section on portland cement manufacturing. Emission factors were developed from the data presented in 62 of these references. A list of the references used to develop emission factors is presented in Table 4-1. The majority of these documents were emission test reports. However, several test report summaries and other technical reports containing emission data also were reviewed. Approximately 40 of the references were provided by the Portland Cement Association for the 1991 update of the $SO_2$ and $NO_x$ emission factors in Section 8.6. These references were a combination of full test reports, excerpts from test reports, and tabular data summaries, and the level of supporting data on testing procedures and process operations varied considerably among these references. Many of the remaining reports were taken from the existing background file for the Section 8.6. Other references reviewed include reports of tests sponsored by EPA to determine the emission characteristics of burning hazardous waste in cement kilns; tests to demonstrate compliance with the boiler and industrial furnace (BIF) regulations of 40 CFR Part 266 for using hazardous waste as a supplemental fuel; and a test to satisfy the requirements of California AB 2588 ("Hot Spots").

The data compiled and the emission factors developed from the data are presented in Tables 4-2 to 4-7, which summarize the data on wet process kilns, long dry process kilns, dry

There appears to be only one BIF test in this table. There are many more in EPA files: you should use them.

TABLE 4-1. SUMMARY OF EMISSION TEST REPORTS AND SUMMARIES USED

| Company name | Plant location | Type of process | Sources tested | Pollutants | Year | Ref. No. |
|---|---|---|---|---|---|---|
| Maule Industries | Hiahleah, FL | wet | clinker cooler<br>kiln | PM, metals<br>PM, metals | 1971 | 1 |
| Ideal Cement | Seattle, WA | wet | clinker cooler<br>kiln | PM, metals<br>PM, metals | 1971 | 2 |
| Ideal Cement | Castle Hayne, NC | wet | finish mill air separator<br>finish grinding mill | PM<br>PM | 1971 | 3 |
| Dragon Cement | Northampton, PA | dry | kiln | PM, SOx, Hg, CO2 | 1971 | 4 |
| Ideal Cement | Houston, TX | wet | clinker cooler<br>finish grinding mill | PM<br>PM | 1971 | 5 |
| Giant Portland Cement | Harleyville, SC | wet | kiln | PM, SO2, NOx, Hg | 1971 | 6 |
| Oregon Portland Cement | Lake Oswego, OR | wet | kiln | PM, SO2 | 1971 | 7 |
| Ideal Cement | Tijeras, NM | dry | raw mill weigh hopper<br>raw mill<br>raw mill air separator<br>finish mill weigh hopper<br>finish mill<br>finish mill air separator | PM, metals<br>PM, metals<br>PM, metals<br>PM, metals<br>PM<br>PM, metals | 1971 | 8 |
| Arizona Portland Cement | Rillito, AZ | NA | primary crushing<br>primary screening<br>limestone transfer<br>secondary screenin and crushing | PM<br>PM<br>PM<br>PM | 1974 | 9 |
| Monarch Cement | Humboldt, KS | preheater | kiln | PM | 1981 | 10 |
| Ideal Basic Industries | Ada, OK | wet | kiln | PM | 1981 | 11 |
| Lone Star Industries | Nazareth, PA | dry | kiln | PM, SO2 | 1977 | 12 |
| Lone Star Industries | Greencastle, IN | wet | kiln | PM, SO2 | 1979 | 13 |
| Lone Star Cement | Roanoke, VA | dry, wet | kiln | PM, CO2 | 1980 | 14 |
| Oklahoma Cement | Pryor, OK | dry | clinker cooler | PM | 1980 | 15 |
| Oklahoma Cement | Pryor, OK | dry | kiln | PM, SO2, CO2 | 1980 | 16 |
| Lone Star Industries | Maryneal, TX | preheater | kiln | SO2, SO3, CO2 | 1980 | 17 |
| Lone Star Industries | New Orleans, LA | wet | kiln | PM, SO2, SO3, NH4, Cl, K, Na, SO4, CO2 | 1980 | 18 |
| Lone Star Industries | Bonner Springs, KS | wet | kiln | PM, SO2, NOx, CO2 | 1981 | 19 |
| Lehigh Portland Cement | Mason City, IO | dry | clinker cooler | PM, CO2 | 1983 | 20 |
| California Portland Cement | Bakersfield, CA | precalciner | kiln | SO2, NOx, CO, CO2 | 1983 | 21 |
| Lehigh Portland Cement | Waco, TX | NS | kiln<br>clinker cooler | PM, SO2, NOx, CO2<br>PM | 1983 | 23 |
| California Portland Cement | Bakersfield, CA | precalciner | kiln<br>clinker cooler | PM, SO2, SO3, NOx CO, CO2, THC<br>PM | 1984 | 24 |
| Leeds Portland Cement | Leeds, AL | dry | kiln<br>clinker cooler | PM, CO2<br>PM, CO2 | 1984 | 25 |

TABLE 4-1. (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| Lehigh Portland Cement | Cementon, NY | wet | kiln | PM, SO2, CO2 | 1984 | 26 |
| CalMatCo | Bakersfield, CA | precalciner | kiln | PM, SO2, SO3, NOx CO, CO2, THC | 1985 | 27 |
| | | | clinker cooler | PM | | |
| Lonestar Florida Holding | Miami, FL | wet | kiln | PM, SO2, NOx, CO2 | 1985 | 28 |
| Lonestar Florida/ Pennsuco | Miami, FL | wet | kiln | PM, SO2, NOx, CO2 | 1981 | 29 |
| Lonestar Florida/ Pennsuco | Miami, FL | wet | kiln | PM, SO2, NOx, CO2 | 1981 | 30 |
| Lone Star Cement | Davenport, CA | precalciner | kiln | PM, SO2, NOx, CO CO2 | 1985 | 31 |
| CalMatCo | Colton, CA | dry | kiln | NOx | 1987 | 35 |
| Riverside Cement | Crestmore, CA | dry | kiln | SO2, NOx, CO | 1981 | 36 |
| | | | | NOx | 1985 | |
| Lafarge Corp. | Alpena, MI | dry | kiln | PM, SO2, NOx, VOC | 1989 | 37 |
| Southwestern Portland Cement | Black Mountain, CA | dry | kiln | SO2, NOx, CO, CO2 | 1984 | 39 |
| Alpha Portland Cement | Cementon, NY | dry | kiln | PM, SO2, HCl | 1982 | 40 |
| Lone Star Industries | New Orleans, LA | wet | kiln | PM, SO2, SO4, NH4, Cl, K, Na, | 1982 | 42 |
| Lone Star Industries | New Orleans, LA | wet | kiln | PM, SO2, SO4, NH4, Cl, K, Na, F, NOx | 1982 | 43 |
| Lone Star Industries | New Orleans, LA | wet | kiln | PM, SO2, SO4, NH4, Cl, Na, CO2 | 1982 | 44 |
| Southwestern Portland Cement | Victorville, CA | wet | kiln | SO2, NOx, CO, CO2 | 1980 | 48 |
| Ash Grove Cement We | Durkee, OR | preheater | kiln | NOx | 1987 | 49 |
| Calaveras Cement | Redding, CA | preheater | kiln | SO2, NOx | 1981 | 50 |
| Texas Cement | Buda, TX | preheater | kiln | PM, SO2, NOx | 1986 | 51 |
| Southwestern Portland Cement | Fairborn, OH | preheater | kiln | PM, SO2, CO2 | 1986 | 52 |
| Florida Mining and Materials | Brooksville, FL | preheater | kiln | PM, SO2, NOx | 1982 | 53 |
| | | | | PM, SO2 | 1983 | |
| | | | | PM, SO2, NOx | 1984 | |
| | | | | PM, SO2, NOx | 1985 | |
| | | | | PM, SO2, NOx, CO2 | 1986 | |
| | | | | PM, SO2, NOx | 1987 | |
| | | | | PM, NOx, CO2 | 1988 | |
| | | | | PM, SO2, NOx, CO2 | 1989 | |
| Southwestern Portland Cement | Kosmosdale, KY | preheater | kiln | PM, SO2, NOx, CO CO2, VOC, HCl | 1989 | 54 |
| Southwestern Portland Cement | Odessa, TX | preheater | kiln | PM, SO2, SO3, NOx, CO2 | 1983 | 55 |
| Ash Grove Cement We | Leamington, UT | precalciner | kiln | PM, SO2, NOx, CO2 | 1989 | 56 |

TABLE 4-1. (continued)

| | | | | | | |
|---|---|---|---|---|---|---|
| CalMatCo | Colton, CA | precalciner | kiln | PM, SO2, NOx | 1983 | 57 |
| | | | | PM, SO2, NOx, CO, SO4, THC | 1984 | |
| | | | | PM, SO2, NOx, CO, SO4, THC | 1985 | |
| | | | | PM, SO2, NOx, CO, SO4, THC | 1986 | |
| | | | | PM, SO2, NOx, CO, SO4, THC | 1987 | |
| | | | | PM, SO2, NOx, CO, SO4, THC | 1988 | |
| | | | | PM, SO2, NOx, CO, SO4, THC | 1989 | |
| Marquette Cement | Cape Girardeau, MO | precalciner | kiln | SO2 | 1982 | 58 |
| Lone Star Industries | Cape Girardeau, MO | precalciner | kiln | SO2 | 1983 | 59 |
| Ash Grove Cement We | Leamington, UT | precalciner | kiln | PM, NOx, CO2 | 1985 | 60 |
| Southwestern Portland Cement | Victorville, CA | precalciner | kiln | PM, SO2, NOx, CO, CO2, THC | 1985 | 61 |
| | | | clinker cooler | PM | | |
| | | | raw mill | PM | | |
| | | | finish mill | PM | | |
| Southwestern Portland Cement | Victorville, CA | precalciner | kiln | PM, SO2, NOx, CO, CO2 | 1985 | 62 |
| | | | raw mill | PM | | |
| | | | raw mill feed belt | PM | | |
| | | | finish mill | PM | | |
| | | | finish mill feed belt | PM | | |
| Southwestern Portland Cement | Victorville, CA | precalciner | kiln | PM, SO2, NOx, CO, CO2 | 1987 | 63 |
| Southwestern Portland Cement | Victorville, CA | precalciner | kiln | PM, SO2, NOx, CO, CO2, NH3, HCl | 1987 | 64 |
| Continental | Hannibal, MO | wet | kiln | SO2, NOx, CO, CO2, 25 organics | 1990 | 65 |
| Ash Grove | Louisville, NE | precalciner | kiln | NOx, CO, CO2, 20 organics | 1990 | 66 |
| Lonestar Florida/ Pennsuco | Miami, FL | wet | kiln | PM, CO2 | 1980 | 67 |
| Lone Star Industries | Maryneal, TX | preheater | kiln | PM, CO2 | 1980 | 69 |
| Kaiser Cement | Walnut Creek, CA | precalciner | kiln | HCl, CO2, 6 metals, 24 organics | 1990 | 74 |
| Lone Star Industries | Cape Girardeau, MO | precalciner | kiln | PM, CO, CO2, THC, HCl, Cl, 11 metals | 1992 | 76 |
| Essrock Materials | Frederick, MD | wet | kiln | PM, SO2, NOx, CO THC, 7 metals, 15 organics | 1991 | 77 |
| Lone Star Industries | Oglesby, IL | dry | kiln | PM, SO2, NOx, CO THC, HCl, 12 metals, 14 organics | 1984 | 78 |

NA = not applicable.
NS = not specified.
THC = total hydrocarbons.

TABLE 4-2. SUMMARY OF TEST DATA FOR PORTLAND CEMENT WET PROCESS KILNS

| Pollutant | Type of control | No. runs(a) | Emission factor, kg/Mg | | | Emission factor, lb/ton | | | Data rating | Ref. No. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Minimum | Maximum | Average | Minimum | Maximum | Average | | |
| COAL-FIRED ROTARY KILNS | | | | | | | | | | |
| filterable PM | none | 4 | 550 | 700 | 630 | 1,100 | 1,400 | 1,250 | D | 11 |
| filterable PM | none | 4 | 55 | 75 | 65 | 110 | 150 | 130 | B | 19 |
| filterable PM | none | 3a | 100 | 230 | 180 | 200 | 450 | 350 | C | 30 |
| filterable PM | ESP | 2 | 0.053 | 0.086 | 0.069 | 0.11 | 0.17 | 0.14 | C | 11 |
| filterable PM | ESP | 3a | 0.034 | 0.079 | 0.050 | 0.068 | 0.16 | 0.10 | C | 67 |
| filterable PM | ESP | 3 | 0.00049 | 0.19 | 0.075 | 0.00098 | 0.38 | 0.15 | C | 13 |
| filterable PM | ESP | 3b | 0.13 | 0.26 | 0.18 | 0.26 | 0.51 | 0.36 | B | 18 |
| filterable PM | ESP | 3c | 0.17 | 0.20 | 0.19 | 0.34 | 0.41 | 0.37 | B | 18 |
| filterable PM | ESP | 7d. | 0.14 | 1.6 | 0.70 | 0.27 | 3.2 | 1.4 | B | 19 |
| filterable PM | ESP | 14 | 0.22 | 1.1 | 0.60 | 0.44 | 2.1 | 1.2 | B | 19 |
| filterable PM | ESP | 4d | 0.17 | 0.95 | 0.42 | 0.33 | 1.9 | 0.83 | B | 19 |
| filterable PM | ESP | 3e | 0.070 | 0.10 | 0.075 | 0.14 | 0.19 | 0.15 | C | 26 |
| filterable PM | ESP | 3a | 0.10 | 0.13 | 0.12 | 0.20 | 0.26 | 0.23 | B | 28 |
| filterable PM | ESP | 3a | 0.080 | 0.13 | 0.10 | 0.16 | 0.26 | 0.20 | C | 29 |
| filterable PM | ESP | 3a | 0.060 | 0.13 | 0.10 | 0.12 | 0.26 | 0.19 | C | 30 |
| filterable PM | ESP | 3e | 0.50 | 0.55 | 0.55 | 1.0 | 1.1 | 1.1 | C | 40 |
| filterable PM | ESP | 3b | 0.018 | 0.37 | 0.16 | 0.04 | 0.73 | 0.32 | B | 42 |
| filterable PM | ESP | 3c | 0.038 | 0.15 | 0.11 | 0.08 | 0.31 | 0.22 | B | 42 |
| filterable PM | ESP | 3b | 0.22 | 0.29 | 0.25 | 0.44 | 0.58 | 0.49 | B | 43 |
| filterable PM | ESP | 3c | 0.065 | 0.10 | 0.084 | 0.13 | 0.20 | 0.17 | B | 44 |
| filterable PM | FF | 3 | 0.21 | 0.26 | 0.23 | 0.43 | 0.53 | 0.46 | C | 7 |
| filterable PM | (b) | 2 | 0.034 | 0.17 | 0.10 | 0.07 | 0.33 | 0.20 | C | 14 |
| cond. inorg. PM | ESP | 3 | 0.050 | 0.17 | 0.11 | 0.10 | 0.33 | 0.21 | B | 13 |
| cond. inorg. PM | FF | 3 | 0.026 | 0.25 | 0.10 | 0.053 | 0.49 | 0.20 | C | 7 |
| cond. inorg. PM | (b) | 2 | 0.10 | 0.19 | 0.14 | 0.20 | 0.37 | 0.29 | C | 14 |
| SO2 | none | 3a | 2.1 | 3.9 | 3.0 | 4.2 | 7.7 | 6.0 | C | 30 |
| SO2 | ESP | 3f | 0.55 | 2.4 | 1.2 | 1.1 | 4.7 | 2.3 | B | 13 |
| SO2 | ESP | 3f | 5.5 | 7.0 | 6.0 | 11 | 14 | 12 | B | 13 |
| SO2 | ESP | 3c | 1.8 | 3.1 | 2.6 | 3.6 | 6.3 | 5.3 | C | 18 |
| SO2 | ESP | 3b | 0.26 | 1.8 | 1.0 | 0.53 | 3.6 | 2.0 | C | 18 |
| SO2 | ESP | 6d | 2.1 | 15 | 11 | 4.1 | 30 | 21 | B | 19 |
| SO2 | ESP | 16 | 2.0 | 11 | 5.5 | 3.9 | 22 | 11 | B | 19 |
| SO2 | ESP | 8d | 3.5 | 10 | 6.0 | 6.9 | 20 | 12 | B | 19 |
| SO2 | ESP | 3e | 8.0 | 10 | 9.0 | 16 | 20 | 18 | C | 26 |
| SO2 | ESP | 3a | 2.1 | 2.3 | 2.2 | 4.2 | 4.5 | 4.4 | B | 28 |
| SO2 | ESP | 3a | 2.2 | 3.5 | 2.8 | 4.4 | 6.9 | 5.5 | C | 29 |
| SO2 | ESP | 3a | 1.9 | 3.3 | 2.7 | 3.8 | 6.5 | 5.4 | C | 30 |
| SO2 | ESP | 3e | 1.3 | 1.6 | 1.4 | 2.5 | 3.1 | 2.8 | C | 40 |
| SO2 | ESP | 3c | 2.2 | 3.2 | 2.8 | 4.4 | 6.5 | 5.6 | C | 42 |
| SO2 | ESP | 3b | 2.1 | 3.6 | 2.8 | 4.3 | 7.1 | 5.6 | C | 42 |
| SO2 | ESP | 3c | 6.8 | 8.5 | 8.0 | 13.6 | 17 | 16 | C | 44 |
| SO2 | ESP | 1 | NA | NA | 13 | NA | NA | 25 | NR | 65 |
| SO2 | FF | 4 | 0.085 | 0.42 | 0.20 | 0.17 | 0.83 | 0.41 | D | 7 |
| NOx | ESP | 3a | 3.2 | 3.5 | 3.4 | 6.3 | 6.9 | 6.7 | B | 28 |
| NOx | ESP | 12a | 1.6 | 4.2 | 3.2 | 3.2 | 8.4 | 6.4 | C | 29 |
| NOx | ESP | 12a | 2.5 | 4.7 | 3.4 | 4.9 | 9.3 | 6.8 | C | 30 |
| NOx | ESP | 3b | 1.7 | 2.9 | 2.1 | 3.4 | 5.8 | 4.3 | B | 43 |
| NOx | ESP | 12c | 1.4 | 2.7 | 1.9 | 2.9 | 5.4 | 3.7 | B | 43 |
| NOx | ESP | 1 | NA | NA | 10 | NA | NA | 20 | NR | 65 |
| CO | ESP | 1 | NA | NA | 1.3 | NA | NA | 2.7 | NR | 65 |
| CO2 | ESP | 3c | 1,070 | 1,110 | 1,090 | 2,130 | 2,210 | 2,180 | B | 18 |
| CO2 | ESP | 3a | 290 | 320 | 310 | 578 | 630 | 610 | C | 67 |
| CO2 | ESP | 3b | 930 | 1,010 | 980 | 1,850 | 2,010 | 1,960 | B | 18 |
| CO2 | ESP | 3e | 780 | 970 | 890 | 1,550 | 1,930 | 1,780 | C | 26 |

TABLE 4-2. (CONTINUED)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CO2 | ESP | 3a | 1,010 | 1,130 | 1,070 | 2,020 | 2,260 | 2,130 | B | 28 |
| CO2 | ESP | 3a | 410 | 450 | 430 | 820 | 890 | 850 | C | 29 |
| CO2 | ESP | 6a | 410 | 490 | 450 | 810 | 970 | 890 | C | 30 |
| CO2 | ESP | 3c | 1,100 | 1,230 | 1,150 | 2,193 | 2,450 | 2,300 | C | 44 |
| CO2 | ESP | 1 | NA | NA | 2,200 | NA | NA | 4,400 | NR | 65 |
| CO2 | (b) | 2 | 26 | 950 | 490 | 51 | 1,900 | 970 | D | 14 |
| Be | ESP | 1 | NA | NA | 2.2E-06 | NA | NA | 4.4E-06 | NR | 2 |
| Cd | ESP | 1 | NA | NA | 0.00019 | NA | NA | 0.00037 | NR | 2 |
| Cl | ESP | 3b | 0.12 | 0.23 | 0.17 | 0.24 | 0.46 | 0.34 | C | 18 |
| Cl | ESP | 3c | 0.15 | 0.29 | 0.25 | 0.31 | 0.58 | 0.49 | C | 18 |
| Cl | ESP | 3b | 0.15 | 0.48 | 0.31 | 0.31 | 0.97 | 0.61 | C | 42 |
| Cl | ESP | 3c | 0.42 | 0.62 | 0.52 | 0.83 | 1.2 | 1.0 | C | 42 |
| Cl | ESP | 3c | ND | ND | 0.55 | ND | ND | 1.1 | C | 43 |
| Cl | ESP | 3c | 0.37 | 0.50 | 0.44 | 0.73 | 1.0 | 0.88 | C | 44 |
| Cr | ESP | 1 | NA | NA | 0.00011 | NA | NA | 0.00022 | NR | 2 |
| Cu | ESP | 1 | NA | NA | 0.00022 | NA | NA | 0.00044 | NR | 2 |
| F | ESP | 3c | ND | ND | 0.00045 | ND | ND | 0.00090 | C | 43 |
| Fe | ESP | 1 | NA | NA | 0.017 | NA | NA | 0.033 | NR | 2 |
| HCl | ESP | 3 | 0.016 | 0.036 | 0.024 | 0.031 | 0.071 | 0.047 | C | 40 |
| K | ESP | 3b | 0.013 | 0.026 | 0.020 | 0.026 | 0.053 | 0.041 | B | 18 |
| K | ESP | 3c | 0.016 | 0.025 | 0.020 | 0.032 | 0.049 | 0.041 | B | 18 |
| K | ESP | 3b | 0.00060 | 0.00082 | 0.00068 | 0.0012 | 0.0016 | 0.0014 | B | 42 |
| K | ESP | 3c | 6.8E-05 | 0.0012 | 0.00047 | 0.00014 | 0.0024 | 0.00094 | B | 42 |
| K | ESP | 3c | ND | ND | 0.00060 | ND | ND | 0.0012 | C | 43 |
| Mn | ESP | 1 | NA | NA | 0.00022 | NA | NA | 0.00044 | NR | 2 |
| NH4 | ESP | 3c | 0.010 | 0.023 | 0.015 | 0.020 | 0.046 | 0.031 | C | 18 |
| NH4 | ESP | 3b | 0.0065 | 0.0094 | 0.0078 | 0.013 | 0.019 | 0.016 | C | 18 |
| NH4 | ESP | 3b | 0.026 | 0.053 | 0.037 | 0.053 | 0.11 | 0.073 | B | 42 |
| NH4 | ESP | 3c | 0.084 | 0.13 | 0.11 | 0.17 | 0.26 | 0.22 | B | 42 |
| NH4 | ESP | 3 | ND | ND | 0.094 | ND | ND | 0.19 | C | 43 |
| NH4 | ESP | 3 | 0.11 | 0.14 | 0.12 | 0.22 | 0.29 | 0.24 | C | 44 |
| NO3 | ESP | 3 | ND | ND | 0.0023 | ND | ND | 0.0046 | C | 43 |
| Na | ESP | 3 | 0.015 | 0.027 | 0.021 | 0.031 | 0.054 | 0.043 | B | 18 |
| Na | ESP | 3 | 0.022 | 0.024 | 0.023 | 0.044 | 0.048 | 0.046 | B | 18 |
| Na | ESP | 3 | 0.00020 | 0.0045 | 0.0016 | 0.0004 | 0.0090 | 0.0032 | B | 42 |
| Na | ESP | 3 | 3.7E-03 | 0.0057 | 0.0044 | 0.0073 | 0.011 | 0.0088 | B | 42 |
| Na | ESP | 3 | ND | ND | 0.0010 | ND | ND | 0.0020 | C | 43 |
| Na | ESP | 3 | 0.052 | 0.094 | 0.077 | 0.10 | 0.19 | 0.15 | C | 44 |
| Ni | ESP | 1 | NA | NA | 0.00022 | NA | NA | 0.00044 | NR | 2 |
| Pb | ESP | 1 | NA | NA | 0.0044 | NA | NA | 0.0088 | NR | 2 |
| SO3 | ESP | 3c | 0.026 | 0.085 | 0.064 | 0.053 | 0.17 | 0.13 | C | 18 |
| SO3 | ESP | 3b | 0.016 | 0.029 | 0.020 | 0.032 | 0.058 | 0.041 | C | 18 |
| SO4 | ESP | 3b | 0.071 | 0.082 | 0.076 | 0.14 | 0.16 | 0.15 | B | 18 |
| SO4 | ESP | 3c | 0.010 | 0.022 | 0.017 | 0.020 | 0.044 | 0.034 | B | 18 |
| SO4 | ESP | 3b | 0.16 | 0.22 | 0.19 | 0.32 | 0.44 | 0.37 | B | 42 |
| SO4 | ESP | 3c | 0.094 | 0.16 | 0.12 | 0.19 | 0.32 | 0.24 | B | 42 |
| SO4 | ESP | 3c | ND | ND | 0.12 | ND | ND | 0.24 | C | 43 |
| SO4 | ESP | 3c | 0.025 | 0.037 | 0.030 | 0.049 | 0.073 | 0.060 | C | 44 |
| V | ESP | 1 | NA | NA | 6.7E-05 | NA | NA | 0.00013 | NR | 2 |
| Zn | ESP | 1 | NA | NA | 0.0094 | NA | NA | 0.019 | NR | 2 |

TABLE 4-2. (CONTINUED)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Acrolein | ESP | 1 | NA | NA | 0.00094 | NA | NA | 0.0019 | NR | 65 |
| Acetone | ESP | 1 | NA | NA | 0.0012 | NA | NA | 0.0024 | NR | 65 |
| Methylene chloride | ESP | 1 | NA | NA | 0.00043 | NA | NA | 0.00085 | NR | 65 |
| Acrylonitrile | ESP | 1 | NA | NA | 0.0016 | NA | NA | 0.0032 | NR | 65 |
| t-1,2-Dichloroethane | ESP | 1 | NA | NA | 2.4E-07 | NA | NA | 4.8E-07 | NR | 65 |
| 1,1 Dichloroethane | ESP | 1 | NA | NA | 1.2E-06 | NA | NA | 2.3E-06 | NR | 65 |
| Methyl ethyl ketone | ESP | 1 | NA | NA | 0.00026 | NA | NA | 0.00051 | NR | 65 |
| Chloroform | ESP | 1 | NA | NA | 5.3E-05 | NA | NA | 0.00011 | NR | 65 |
| 1,1,1-Trichloroethane | ESP | 1 | NA | NA | 4.6E-05 | NA | NA | 9.2E-05 | NR | 65 |
| Carbon tetrachloride | ESP | 1 | NA | NA | 2.9E-06 | NA | NA | 5.8E-06 | NR | 65 |
| Benzene | ESP | 1 | NA | NA | 0.0029 | NA | NA | 0.0058 | NR | 65 |
| 1,2-Dichloroethane | ESP | 1 | NA | NA | 2.0E-05 | NA | NA | 4.1E-05 | NR | 65 |
| Trichloroethene | ESP | 1 | NA | NA | 2.0E-05 | NA | NA | 4.1E-05 | NR | 65 |
| 1,2-Dichloropropane | ESP | 1 | NA | NA | 2.9E-06 | NA | NA | 5.8E-06 | NR | 65 |
| p-Dioxane | ESP | 1 | NA | NA | 0.00016 | NA | NA | 0.00032 | NR | 65 |
| Bromodichloromethane | ESP | 1 | NA | NA | 2.9E-05 | NA | NA | 5.8E-05 | NR | 65 |
| Toluene | ESP | 1 | NA | NA | 0.00094 | NA | NA | 0.0019 | NR | 65 |
| t-1,3-Dichloropropene | ESP | 1 | NA | NA | 1.7E-06 | NA | NA | 3.4E-06 | NR | 65 |
| 1,1,2-Trichloroethane | ESP | 1 | NA | NA | 2.0E-05 | NA | NA | 4.1E-05 | NR | 65 |
| Tetrachloroethene | ESP | 1 | NA | NA | 1.1E-05 | NA | NA | 2.1E-05 | NR | 65 |
| Dibromochloromethane | ESP | 1 | NA | NA | 3.6E-06 | NA | NA | 7.1E-06 | NR | 65 |
| Chlorobenzene | ESP | 1 | NA | NA | 0.00019 | NA | NA | 0.00037 | NR | 65 |
| Ethylbenzene | ESP | 1 | NA | NA | 0.00015 | NA | NA | 0.00030 | NR | 65 |
| Bromoform | ESP | 1 | NA | NA | 6.5E-06 | NA | NA | 1.3E-05 | NR | 65 |
| 1,1,2,2-Tetrachrloroethane | ESP | 1 | NA | NA | 5.8E-05 | NA | NA | 0.00012 | NR | 65 |
| Benzyl alcohol | ESP | 1 | NA | NA | 0.0041 | NA | NA | 0.0082 | NR | 65 |
| Benzoic acid | ESP | 1 | NA | NA | 0.0058 | NA | NA | 0.012 | NR | 65 |
| Naphthalene | ESP | 1 | NA | NA | 0.00085 | NA | NA | 0.0017 | NR | 65 |
| 2-Methylnaphthalene | ESP | 1 | NA | NA | 0.00029 | NA | NA | 0.00058 | NR | 65 |
| Phenanthrene | ESP | 1 | NA | NA | 0.00012 | NA | NA | 0.00024 | NR | 65 |
| CDD/CDF (total) | ESP | 1 | NA | NA | 6.3E-07 | NA | NA | 1.3E-06 | NR | 65 |
| GAS-FIRED ROTARY KILNS | | | | | | | | | | |
| filterable PM | ESP | 3 | 0.54 | 1.5 | 1.0 | 1.1 | 3.1 | 2.0 | C | 1 |
| filterable PM | ESP | 2 | 0.72 | 0.78 | 0.75 | 1.4 | 1.6 | 1.5 | C | 2 |
| filterable PM | FF | 1 | NA | NA | 0.46 | NA | NA | 0.92 | NR | 6 |
| cond. inorg. PM | ESP | 3 | 0.054 | 0.16 | 0.10 | 0.11 | 0.32 | 0.20 | C | 1 |
| cond. inorg. PM | ESP | 2 | 0.063 | 0.09 | 0.075 | 0.13 | 0.17 | 0.15 | C | 2 |
| SO2 | FF | 2 | 4.8 | 6.4 | 5.6 | 9.7 | 13 | 11 | D | 6 |
| NOx | ESP | 4 | 0.71 | 2.2 | 1.4 | 1.4 | 4.4 | 2.9 | C | 1 |
| NOx | FF | 2 | 1.6 | 4.3 | 3.0 | 3.2 | 8.5 | 6.0 | D | 6 |
| Cr | ESP | 1 | NA | NA | 0.0020 | NA | NA | 0.0039 | NR | 1 |
| Cu | ESP | 1 | NA | NA | 0.00015 | NA | NA | 0.00031 | NR | 1 |
| Fe | ESP | 1 | NA | NA | 0.0062 | NA | NA | 0.012 | NR | 1 |
| Hg | FF | 2 | 1.3E-05 | 2.6E-05 | 2.0E-05 | 2.6E-05 | 5.3E-05 | 3.9E-05 | D | 6 |
| Mn | ESP | 1 | NA | NA | 7.7E-05 | NA | NA | 0.00015 | NR | 1 |
| Ni | ESP | 1 | NA | NA | 0.0013 | NA | NA | 0.0026 | NR | 1 |
| Pb | ESP | 1 | NA | NA | 0.00048 | NA | NA | 0.00097 | NR | 1 |
| Sr | ESP | 1 | NA | NA | 0.0017 | NA | NA | 0.0034 | NR | 1 |
| V | ESP | 1 | NA | NA | 8.2E-05 | NA | NA | 0.00016 | NR | 1 |

TABLE 4-2. (CONTINUED)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| OIL-FIRED ROTARY KILNS | | | | | | | | | |
| cond. inorg. PM | FF | 1 | NA | NA | 0.57 | NA | NA | 1.1 | NR | 6 |
| SO2 | none | 1 | NA | NA | 16 | NA | NA | 32 | NR | 6 |
| SO2 | FF | 2 | 7.2 | 11 | 8.9 | 14 | 21 | 18 | D | 6 |
| COAL- AND OIL-FIRED ROTARY KILNS | | | | | | | | | | |
| filterable PM | ESP | 3 | 0.35 | 0.46 | 0.42 | 0.69 | 0.91 | 0.84 | B | 77 |
| cond. inorg. PM | ESP | 3 | 0.021 | 0.025 | 0.024 | 0.042 | 0.050 | 0.047 | B | 77 |
| SO2 | ESP | 3 | 0.55 | 2.0 | 1.2 | 1.1 | 4.0 | 2.3 | B | 77 |
| NOx | ESP | 3 | 8.5 | 11 | 10 | 17 | 22 | 20 | B | 77 |
| CO | ESP | 3 | 0.046 | 0.080 | 0.060 | 0.092 | 0.16 | 0.12 | B | 77 |
| CO2 | ESP | 3 | 1,250 | 1,350 | 1,300 | 2,500 | 2,700 | 2,600 | B | 77 |
| total hydrocarbons | ESP | 3 | 0.014 | 0.015 | 0.014 | 0.027 | 0.029 | 0.028 | B | 77 |
| Ba | ESP | 3 | 0.00014 | 0.00025 | 0.00018 | 0.00027 | 0.00049 | 0.00035 | B | 77 |
| Cd | ESP | 3 | 2.7E-06 | 6.5E-06 | 4.2E-06 | 5.4E-06 | 1.3E-05 | 8.3E-06 | B | 77 |
| Cr | ESP | 2 | 1.6E-06 | 6.0E-06 | 3.9E-06 | 3.2E-06 | 1.2E-05 | 7.7E-06 | C | 77 |
| Hg | ESP | 3 | 7.5E-05 | 0.00014 | 0.00011 | 0.00015 | 0.00027 | 0.00022 | B | 77 |
| Ni | ESP | 1 | NA | NA | 1.4E-05 | NA | NA | 2.7E-05 | NR | 77 |
| Pb | ESP | 3 | 0.00021 | 0.00048 | 0.00036 | 0.00042 | 0.00096 | 0.00071 | B | 77 |
| Zn | ESP | 3 | 0.00019 | 0.00037 | 0.00027 | 0.00038 | 0.00073 | 0.00054 | B | 77 |
| 2-butanone | ESP | 3 | 3.7E-06 | 2.9E-05 | 2.0E-05 | 7.3E-06 | 5.8E-05 | 3.9E-05 | B | 77 |
| acetone | ESP | 3 | 4.7E-05 | 0.00033 | 0.00019 | 9.3E-05 | 0.00065 | 0.00037 | B | 77 |
| benzene | ESP | 3 | 0.0014 | 0.0019 | 0.0016 | 0.0027 | 0.0037 | 0.0031 | B | 77 |
| benzoic acid | ESP | 3 | 0.0014 | 0.0021 | 0.0018 | 0.0028 | 0.0042 | 0.0035 | B | 77 |
| bis(2-ethylhexyl)phthalate | ESP | 3 | 3.1E-05 | 7.0E-05 | 4.8E-05 | 6.1E-05 | 0.00014 | 9.5E-05 | B | 77 |
| bromomethane | ESP | 2 | 1.5E-05 | 2.9E-05 | 2.2E-05 | 2.9E-05 | 5.8E-05 | 4.3E-05 | C | 77 |
| carbon disulfide | ESP | 3 | 5.0E-05 | 6.0E-05 | 5.5E-05 | 0.00010 | 0.00012 | 0.00011 | B | 77 |
| chlorobenzene | ESP | 2 | 5.5E-06 | 1.1E-05 | 8.0E-06 | 1.1E-05 | 2.1E-05 | 1.6E-05 | C | 77 |
| chloromethane | ESP | 3 | 8.5E-05 | 0.00029 | 0.00019 | 0.00017 | 0.00057 | 0.00038 | B | 77 |
| di-n-butylphthalate | ESP | 3 | 1.5E-05 | 2.4E-05 | 2.1E-05 | 3.0E-05 | 4.7E-05 | 4.1E-05 | B | 77 |
| ethylbenzene | ESP | 3 | 5.5E-06 | 1.5E-05 | 9.5E-06 | 1.1E-05 | 2.9E-05 | 1.9E-05 | B | 77 |
| naphthanlene | ESP | 3 | 6.0E-05 | 0.00015 | 0.00011 | 0.00012 | 0.00029 | 0.00022 | B | 77 |
| phenol | ESP | 3 | 4.5E-05 | 6.0E-05 | 5.5E-05 | 8.9E-05 | 0.00012 | 0.00011 | B | 77 |
| toluene | ESP | 3 | 0.00060 | 0.0014 | 0.00010 | 0.0012 | 0.0028 | 0.00019 | B | 77 |
| xylenes | ESP | 3 | 2.0E-05 | 0.00012 | 0.00007 | 4.0E-05 | 0.00023 | 0.00013 | B | 77 |

ESP = electrostatic precipitator.

FF = fabric filter.

NA = not applicable.

NR = not rated.

(a) Multiple tests conducted on the same kiln indicated by a-e.

(b) Cooling tower with multiclone and ESP.

TABLE 4-3. SUMMARY OF TEST DATA FOR PORTLAND CEMENT LONG DRY PROCESS KILNS

| Pollutant | Type of control | No. runs | Emission factor, kg/Mg |  |  | Emission factor, lb/ton |  |  | Data rating | Ref. No. |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Minimum | Maximum | Average | Minimum | Maximum | Average |  |  |
| filterable PM | ESP | 3 | 0.12 | 0.46 | 0.24 | 0.24 | 0.92 | 0.48 | B | 12 |
| filterable PM | ESP | 3 | 0.065 | 0.17 | 0.11 | 0.13 | 0.33 | 0.21 | B | 12 |
| filterable PM | ESP | 2 | 0.600 | 1.35 | 0.95 | 1.2 | 2.7 | 1.9 | D | 78 |
| filterable PM | FF | 2 | 0.044 | 0.049 | 0.046 | 0.088 | 0.10 | 0.093 | C | 4 |
| filterable PM | FF | 3 | 0.090 | 0.11 | 0.10 | 0.18 | 0.21 | 0.20 | A | 16 |
| filterable PM | FF | 3 | ND | ND | 0.10 | ND | ND | 0.19 | C | 37 |
| filterable PM | (a) | 6 | 0.55 | 0.80 | 0.65 | 1.1 | 1.6 | 1.3 | B | 14 |
| filterable PM | (a) | 6 | 0.28 | 2.0 | 0.85 | 0.56 | 4.0 | 1.7 | B | 14 |
| filterable PM | (a) | 6 | 0.50 | 0.80 | 0.65 | 1.0 | 1.6 | 1.3 | B | 14 |
| cond. inorg. PM | ESP | 3 | 0.19 | 0.70 | 0.41 | 0.37 | 1.4 | 0.82 | B | 12 |
| cond. inorg. PM | ESP | 3 | 0.10 | 0.18 | 0.13 | 0.20 | 0.35 | 0.26 | B | 12 |
| cond. inorg. PM | FF | 2 | 0.088 | 0.10 | 0.10 | 0.18 | 0.19 | 0.19 | C | 4 |
| cond. inorg. PM | FF | 3 | 0.43 | 0.49 | 0.45 | 0.85 | 0.97 | 0.89 | A | 16 |
| cond. inorg. PM | (a) | 6 | 0.090 | 0.20 | 0.15 | 0.18 | 0.39 | 0.29 | B | 14 |
| cond. inorg. PM | (a) | 6 | 0.0026 | 0.21 | 0.11 | 0.0051 | 0.41 | 0.21 | B | 14 |
| cond. inorg. PM | (a) | 6 | 0.10 | 0.20 | 0.17 | 0.20 | 0.40 | 0.33 | B | 14 |
| SO2 | ESP | 8 | 11 | 16 | 14 | 22 | 32 | 27 | B | 12 |
| SO2 | ESP | 4 | 12 | 17 | 14 | 24 | 33 | 28 | B | 12 |
| SO2 | ESP | 2 | 0.080 | 0.011 | 0.046 | 0.16 | 0.022 | 0.092 | C | 78 |
| SO2 | FF | 3 | 1.8 | 3.5 | 2.7 | 3.7 | 7.0 | 5.4 | B | 4 |
| SO2 | FF | 3 | 0.080 | 0.41 | 0.19 | 0.16 | 0.81 | 0.38 | D | 16 |
| SO2 | FF | 3 | 0.13 | 0.27 | 0.20 | 0.26 | 0.54 | 0.40 | B | 36 |
| SO2 | FF | 6 | 1.9 | 5.0 | 3.4 | 3.8 | 10 | 6.7 | B | 37 |
| SO2 | FF | 5 | 0.010 | 0.45 | 0.12 | 0.019 | 0.90 | 0.24 | D | 39 |
| NOx | FF | 2 | 0.96 | 1.9 | 1.44 | 1.9 | 3.8 | 2.9 | C | 4 |
| NOx | FF | 3 | 7.0 | 7.5 | 7.0 | 14 | 15 | 14 | D | 36 |
| NOx | FF | 3 | 2.3 | 7.0 | 4.6 | 4.5 | 14 | 9.2 | B | 36 |
| NOx | FF | (b) | NA | NA | 2.9 | NA | NA | 5.8 | B | 36 |
| NOx | FF | 3 | 1.7 | 2.9 | 2.2 | 3.4 | 5.8 | 4.3 | B | 37 |
| NOx | FF | 6 | 2.3 | 3.7 | 2.8 | 4.5 | 7.3 | 5.5 | D | 39 |
| NOx | ESP | 2 | 3.0 | 3.3 | 3.2 | 6.0 | 6.6 | 6.3 | C | 78 |
| NOx | NS | 3 | 3.3 | 3.5 | 3.4 | 6.5 | 6.9 | 6.7 | C | 35 |
| NOx | NS | 81 | 1.7 | 5.0 | 3.4 | 3.4 | 10 | 6.7 | C | 35 |
| CO | ESP | 2 | 0.050 | 0.060 | 0.055 | 0.10 | 0.12 | 0.11 | C | 78 |
| CO | FF | 3 | 0.10 | 0.10 | 0.10 | 0.20 | 0.20 | 0.20 | D | 36 |
| CO | FF | 1 | NA | NA | 0.44 | NA | NA | 0.87 | NR | 39 |
| CO2 | ESP | 2 | 950 | 1,000 | 1,000 | 1,900 | 2,000 | 2,000 | C | 78 |
| CO2 | FF | 2 | 360 | 472 | 416 | 720 | 944 | 832 | C | 4 |
| CO2 | FF | 3 | 825 | 935 | 895 | 1,650 | 1,870 | 1,790 | C | 16 |
| CO2 | FF | 6 | 765 | 1,400 | 1,000 | 1,530 | 2,800 | 2,000 | D | 39 |
| CO2 | (a) | 6 | 760 | 1,125 | 900 | 1,520 | 2,250 | 1,800 | B | 14 |
| CO2 | (a) | 6 | 830 | 1,410 | 1,030 | 1,660 | 2,820 | 2,060 | B | 14 |
| CO2 | (a) | 6 | 950 | 1,145 | 1,070 | 1,900 | 2,290 | 2,140 | B | 14 |
| total VOC's | FF | 3 | ND | ND | 0.23 | ND | ND | 0.45 | C | 37 |
| total VOC's | FF | 3 | ND | ND | 0.024 | ND | ND | 0.048 | C | 37 |
| total hydrocarbons | ESP | 2 | 0.0042 | 0.0047 | 0.0044 | 0.0083 | 0.0093 | 0.0088 | C | 78 |
| HCl | ESP | 2 | 0.019 | 0.031 | 0.025 | 0.038 | 0.062 | 0.050 | D | 78 |
| Al | ESP | 2 | 0.0037 | 0.0090 | 0.0065 | 0.0073 | 0.018 | 0.013 | D | 78 |
| As | ESP | 2 | 5.5E-06 | 7.0E-06 | 6.5E-06 | 1.1E-05 | 1.4E-05 | 1.3E-05 | D | 78 |
| Ca | ESP | 2 | 0.085 | 0.16 | 0.12 | 0.17 | 0.31 | 0.24 | D | 78 |
| Cd | ESP | 2 | 1.6E-05 | 2.8E-05 | 2.2E-05 | 3.1E-05 | 5.6E-05 | 4.3E-05 | D | 78 |
| Cr | ESP | 1 | NA | NA | 0.00013 | NA | NA | 0.00025 | NR | 78 |
| Fe | ESP | 2 | 0.0065 | 0.011 | 0.0085 | 0.013 | 0.021 | 0.017 | D | 78 |
| Hg | ESP | 2 | 1.6E-06 | 3.0E-06 | 2.3E-06 | 3.2E-06 | 5.9E-06 | 4.6E-06 | D | 78 |
| Hg | FF | 3 | 9.6E-06 | 2.2E-05 | 1.4E-05 | 1.9E-05 | 4.3E-05 | 2.9E-05 | C | 4 |

TABLE 4-3. (continued)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Mn | ESP | 2 | 0.00032 | 0.00055 | 0.00043 | 0.00063 | 0.0011 | 0.00086 | D | 78 |
| Pb | ESP | 2 | 5.0E-05 | 1.1E-04 | 8.0E-05 | 0.00010 | 0.00021 | 0.00016 | D | 78 |
| Se | ESP | 2 | 5.0E-05 | 0.00010 | 7.5E-05 | 0.00010 | 0.00020 | 0.00015 | D | 78 |
| Tl | ESP | 2 | 3.2E-04 | 4.8E-05 | 0.00019 | 0.00063 | 9.6E-05 | 0.00037 | D | 78 |
| Zn | ESP | 2 | 7.0E-05 | 3.4E-05 | 5.0E-05 | 0.00014 | 6.8E-05 | 0.00010 | D | 78 |
| freon 113 | ESP | 2 | 2.3E-05 | 2.8E-05 | 2.5E-05 | 4.5E-05 | 5.5E-05 | 5E-05 | C | 78 |
| toluene | ESP | 2 | 9.5E-05 | 0.00017 | 0.00013 | 0.00019 | 0.00033 | 0.00026 | C | 78 |
| mehtylethlyketone | ESP | 2 | 8.0E-06 | 1.2E-05 | 1.0E-05 | 1.6E-05 | 2.3E-05 | 2.0E-05 | C | 78 |
| 1,1,1, trichloroethylene | ESP | 1 | NA | NA | 2.2E-06 | NA | NA | 4.3E-06 | NR | 78 |
| methylene chloride | ESP | 2 | 0.00011 | 0.00039 | 0.00025 | 0.00021 | 0.00078 | 0.00049 | C | 78 |
| styrene | ESP | 2 | 3.6E-07 | 1.1E-06 | 7.5E-07 | 7.2E-07 | 2.2E-06 | 1.5E-06 | D | 78 |
| ethylbenzene | ESP | 2 | 3.6E-07 | 5.5E-07 | 4.6E-07 | 7.2E-07 | 1.1E-06 | 9.2E-07 | D | 78 |
| C3 benzenes | ESP | 2 | 2.3E-06 | 3.6E-07 | 1.3E-06 | 4.5E-06 | 7.2E-07 | 2.6E-06 | D | 78 |
| C4 benzenes | ESP | 2 | 3.6E-07 | 5.5E-06 | 3.0E-06 | 7.2E-07 | 1.1E-05 | 6.0E-06 | D | 78 |
| C6 benzenes | ESP | 2 | 3.6E-07 | 5.5E-07 | 4.6E-07 | 7.2E-07 | 1.1E-06 | 9.2E-07 | D | 78 |
| biphenyl | ESP | 2 | 2.2E-06 | 3.9E-06 | 3.1E-06 | 4.3E-06 | 7.8E-06 | 6.1E-06 | D | 78 |
| benzaldehyde | ESP | 2 | 2.9E-06 | 2.2E-05 | 1.2E-05 | 5.7E-06 | 4.3E-05 | 2.4E-05 | D | 78 |
| naphthalene | ESP | 2 | 3.6E-06 | 2.0E-05 | 1.2E-05 | 7.2E-06 | 4E-05 | 2.4E-05 | D | 78 |
| methylnaphthalene | ESP | 2 | 1.5E-06 | 2.8E-06 | 2.1E-06 | 2.9E-06 | 5.6E-06 | 4.2E-06 | D | 78 |

ESP = electrostatic precipitator.

FF = fabric filter.

ND = no data.

NR = not rated.

NS = not specified.

(a) Cooling tower with multiclone and ESP.

(b) Multiple CEM readings.

TABLE 4-4. SUMMARY OF TEST DATA FOR PORTLAND CEMENT DRY PREHEATER PROCESS KILNS

| Pollutant | Type of control | No. runs | Emission factor, kg/Mg | | | Emission factor, lb/ton | | | Data rating | Ref. No. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Minimum | Maximum | Average | Minimum | Maximum | Average | | |
| filterable PM | none | 4 | 120 | 130 | 125 | 240 | 260 | 250 | A | 10 |
| filterable PM | ESP | 4 | 0.10 | 0.15 | 0.13 | 0.20 | 0.31 | 0.26 | B | 25 |
| filterable PM | FF | 2 | 0.37 | 0.52 | 0.45 | 0.74 | 1.0 | 0.89 | C | 10 |
| filterable PM | FF | 3 | 0.090 | 0.13 | 0.10 | 0.18 | 0.25 | 0.20 | C | 51 |
| filterable PM | FF | 3 | 0.085 | 0.12 | 0.10 | 0.17 | 0.23 | 0.19 | B | 52 |
| filterable PM | FF | 7 | 0.025 | 0.10 | 0.050 | 0.049 | 0.19 | 0.10 | C | 53 |
| filterable PM | FF | 3 | 0.022 | 0.045 | 0.031 | 0.044 | 0.090 | 0.063 | C | 69 |
| filterable PM | FF | 2 | 0.065 | 0.077 | 0.071 | 0.13 | 0.15 | 0.14 | C | 69 |
| filterable PM | FF | 3 | 0.071 | 0.074 | 0.072 | 0.14 | 0.15 | 0.14 | C | 69 |
| filterable PM | FF | 9 | 0.055 | 0.16 | 0.11 | 0.11 | 0.31 | 0.22 | B | 54 |
| filterable PM | FF | 3 | 0.13 | 0.16 | 0.14 | 0.25 | 0.31 | 0.28 | B | 55 |
| cond. inorg. PM | FF | 3 | 0.010 | 0.023 | 0.017 | 0.020 | 0.045 | 0.033 | B | 55 |
| SO2 | FF | 3 | 0.50 | 1.1 | 0.75 | 1.0 | 2.2 | 1.5 | C | 51 |
| SO2 | FF | 3 | 1.0 | 1.1 | 1.0 | 1.9 | 2.2 | 2.0 | B | 52 |
| SO2 | FF | 10 | 0.0080 | 0.085 | 0.042 | 0.016 | 0.17 | 0.083 | C | 53 |
| SO2 | FF | 8 | 0.028 | 0.11 | 0.055 | 0.055 | 0.22 | 0.11 | B | 54 |
| SO2 | FF | 3 | 0.0025 | 0.0027 | 0.0026 | 0.0050 | 0.0053 | 0.0052 | C | 55 |
| SO2 | NS | NS | NA | NA | 0.43 | NA | NA | 0.85 | D | 50 |
| NOx | ESP | 5 | 1.8 | 3.3 | 2.5 | 3.5 | 6.6 | 5.0 | B | 49 |
| NOx | FF | 3 | 1.9 | 2.0 | 1.9 | 3.7 | 3.9 | 3.8 | C | 51 |
| NOx | FF | 9 | 0.55 | 3.0 | 1.2 | 1.1 | 6.0 | 2.4 | C | 53 |
| NOx | FF | 9 | 2.5 | 3.3 | 2.9 | 5.0 | 6.5 | 5.8 | B | 54 |
| NOx | FF | 3 | 2.7 | 3.3 | 3.1 | 5.4 | 6.5 | 6.2 | B | 55 |
| NOx | NS | NS | ND | ND | 0.17 | ND | ND | 0.34 | D | 50 |
| CO | FF | 9 | 0.26 | 1.2 | 0.49 | 0.52 | 2.4 | 0.98 | B | 54 |
| CO2 | ESP | 4 | 833 | 867 | 850 | 1,666 | 1,734 | 1,700 | B | 25 |
| CO2 | FF | 3 | 842 | 944 | 901 | 1,683 | 1,887 | 1,802 | B | 17 |
| CO2 | FF | 3 | 935 | 1,054 | 1,003 | 1,870 | 2,108 | 2,006 | B | 17 |
| CO2 | FF | 3 | 986 | 1,012 | 1,003 | 1,972 | 2,023 | 2,006 | B | 17 |
| CO2 | FF | 3 | 885 | 915 | 900 | 1,770 | 1,830 | 1,800 | B | 52 |
| CO2 | FF | 3 | 485 | 940 | 785 | 970 | 1,880 | 1,570 | C | 53 |
| CO2 | FF | 2 | 867 | 1,071 | 969 | 1,734 | 2,142 | 1,938 | C | 69 |
| CO2 | FF | 3 | 731 | 808 | 782 | 1,462 | 1,615 | 1,564 | B | 69 |
| CO2 | FF | 3 | 604 | 969 | 765 | 1,207 | 1,938 | 1,530 | B | 69 |
| CO2 | FF | 9 | 795 | 985 | 915 | 1,590 | 1,970 | 1,830 | B | 54 |
| CO2 | FF | 3 | 1,039 | 1,120 | 1,067 | 2,078 | 2,239 | 2,134 | C | 55 |
| total hydrocarbons | FF | 9 | 0.070 | 0.13 | 0.090 | 0.14 | 0.25 | 0.18 | B | 54 |
| VOC | FF | 9 | 0.055 | 0.19 | 0.13 | 0.11 | 0.37 | 0.25 | D | 54 |
| SO3 | FF | 3 | 0.0057 | 0.017 | 0.011 | 0.011 | 0.034 | 0.022 | B | 17 |
| SO3 | FF | 3 | 0.0094 | 0.026 | 0.016 | 0.019 | 0.053 | 0.032 | B | 17 |
| SO3 | FF | 3 | 0.0054 | 0.0060 | 0.0057 | 0.011 | 0.012 | 0.011 | B | 17 |
| SO3 | FF | 3 | 0.0025 | 0.0064 | 0.0039 | 0.0050 | 0.0128 | 0.0077 | C | 55 |
| HCl | FF | 9 | 0.010 | 0.029 | 0.018 | 0.019 | 0.058 | 0.035 | D | 54 |

ESP = electrostatic precipator.

FF = fabric filter.

NS = not specified.

NA = not applicable.

TABLE 4-5. SUMMARY OF TEST DATA FOR PORTLAND CEMENT DRY PREHEATER/PRECALCINER PROCESS KILNS

| Pollutant | Type of control | No. runs(a) | Emission factor, kg/Mg |  |  | Emission factor, lb/ton |  |  | Data rating | Ref. No. |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Minimum | Maximum | Average | Minimum | Maximum | Average |  |  |
| filterable PM | ESP | 3 | 0.017 | 0.034 | 0.024 | 0.034 | 0.068 | 0.048 | B | 31 |
| filterable PM | FF | 3a | 0.018 | 0.038 | 0.026 | 0.036 | 0.077 | 0.053 | B | 24 |
| filterable PM | FF | 3a | 0.010 | 0.017 | 0.014 | 0.020 | 0.034 | 0.029 | B | 27 |
| filterable PM | FF | 3b | 0.042 | 0.055 | 0.050 | 0.083 | 0.11 | 0.099 | C | 57 |
| filterable PM | FF | 3b | 0.041 | 0.050 | 0.046 | 0.082 | 0.10 | 0.091 | C | 57 |
| filterable PM | FF | 3b | 0.025 | 0.037 | 0.029 | 0.049 | 0.073 | 0.058 | C | 57 |
| filterable PM | FF | 3b | 0.033 | 0.043 | 0.039 | 0.066 | 0.086 | 0.077 | C | 57 |
| filterable PM | FF | 2b | 0.049 | 0.060 | 0.055 | 0.097 | 0.12 | 0.11 | C | 57 |
| filterable PM | FF | 3b | 0.023 | 0.041 | 0.033 | 0.046 | 0.081 | 0.066 | C | 57 |
| filterable PM | FF | 3b | 0.012 | 0.022 | 0.018 | 0.024 | 0.043 | 0.036 | C | 57 |
| filterable PM | FF | 3c | 0.0094 | 0.014 | 0.011 | 0.019 | 0.027 | 0.022 | B | 61 |
| filterable PM | FF | 3c | 0.016 | 0.060 | 0.018 | 0.032 | 0.12 | 0.035 | B | 62 |
| filterable PM | FF | 3c | 0.013 | 0.016 | 0.015 | 0.026 | 0.032 | 0.031 | B | 63 |
| filterable PM | FF | 6 | 0.0026 | 0.0072 | 0.0057 | 0.0051 | 0.014 | 0.011 | B | 64 |
| filterable PM | FF | 3d | 0.12 | 0.46 | 0.26 | 0.24 | 0.91 | 0.52 | D | 56 |
| filterable PM | FF | 2d | 0.12 | 0.13 | 0.13 | 0.24 | 0.25 | 0.25 | D | 60 |
| filterable PM | FF | 3 | 0.11 | 0.14 | 0.12 | 0.21 | 0.27 | 0.24 | A | 76 |
| cond. inorg. PM | ESP | 3 | 0.13 | 0.17 | 0.14 | 0.26 | 0.34 | 0.29 | B | 31 |
| cond. inorg. PM | FF | 3a | 0.0020 | 0.0094 | 0.0045 | 0.0039 | 0.019 | 0.0090 | B | 24 |
| cond. inorg. PM | FF | 3a | 0.0029 | 0.0076 | 0.0055 | 0.0058 | 0.015 | 0.011 | B | 27 |
| cond. inorg. PM | FF | 3 | 0.015 | 0.032 | 0.021 | 0.031 | 0.065 | 0.043 | B | 64 |
| cond. inorg. PM | FF | 3d | 0.12 | 0.19 | 0.14 | 0.23 | 0.37 | 0.28 | D | 56 |
| cond. inorg. PM | FF | 2d | 0.065 | 0.070 | 0.065 | 0.13 | 0.14 | 0.13 | D | 60 |
| SO2 | ESP | 3 | 0.29 | 0.32 | 0.31 | 0.58 | 0.65 | 0.63 | B | 31 |
| SO2 | ESP | 3 | 1.4 | 1.5 | 1.4 | 2.7 | 3.1 | 2.9 | B | 58 |
| SO2 | FF | 3a | 0.43 | 0.43 | 0.43 | 0.85 | 0.85 | 0.85 | C | 21 |
| SO2 | FF | 3a | 0.53 | 0.55 | 0.54 | 1.1 | 1.1 | 1.1 | B | 24 |
| SO2 | FF | 3a | 0.13 | 0.14 | 0.14 | 0.26 | 0.27 | 0.27 | B | 27 |
| SO2 | FF | 3b | 0.24 | 0.30 | 0.27 | 0.47 | 0.59 | 0.53 | C | 57 |
| SO2 | FF | 3b | 0.48 | 0.50 | 0.50 | 0.95 | 1.0 | 1.0 | C | 57 |
| SO2 | FF | 3b | 0.50 | 0.55 | 0.50 | 0.99 | 1.1 | 1.0 | C | 57 |
| SO2 | FF | 3b | 0.12 | 0.13 | 0.13 | 0.24 | 0.25 | 0.3 | C | 57 |
| SO2 | FF | 3b | 0.70 | 0.75 | 0.75 | 1.4 | 1.5 | 1.5 | C | 57 |
| SO2 | FF | 3b | 0.29 | 0.43 | 0.35 | 0.58 | 0.85 | 0.70 | C | 57 |
| SO2 | FF | 3b | 0.36 | 0.40 | 0.39 | 0.72 | 0.79 | 0.8 | C | 57 |
| SO2 | FF | 6c | 1.6 | 2.5 | 2.0 | 3.2 | 4.9 | 4.1 | B | 61 |
| SO2 | FF | 3c | 0.034 | 0.075 | 0.055 | 0.068 | 0.15 | 0.11 | B | 62 |
| SO2 | FF | 3c | 0.014 | 0.017 | 0.015 | 0.027 | 0.034 | 0.031 | B | 63 |
| SO2 | FF | 3 | 0.018 | 0.020 | 0.020 | 0.036 | 0.041 | 0.039 | B | 64 |
| SO2 | FF | 3d | 2.6 | 2.2 | 2.2 | 4.0 | 5.1 | 4.4 | D | 56 |
| SO2 | ST | (b) | ND | ND | 0.60 | ND | ND | 1.2 | C | 59 |
| SO2 | ST+ESP | (b) | ND | ND | 0.40 | ND | ND | 0.79 | C | 59 |
| NOx | ESP | 3 | 1.0 | 1.1 | 1.1 | 2.0 | 2.2 | 2.2 | B | 31 |
| NOx | ESP | 1 | NA | NA | 1.6 | NA | NA | 3.2 | NR | 65 |
| NOx | FF | 3a | 1.4 | 1.6 | 1.5 | 2.9 | 3.2 | 3.1 | C | 21 |
| NOx | FF | 3a | 1.8 | 1.9 | 1.9 | 3.6 | 3.7 | 3.7 | B | 24 |
| NOx | FF | 3a | 2.1 | 2.1 | 2.1 | 4.3 | 4.3 | 4.3 | B | 27 |
| NOx | FF | 3b | 1.3 | 1.5 | 1.4 | 2.6 | 3.0 | 2.8 | C | 57 |
| NOx | FF | 3b | 1.7 | 1.8 | 1.7 | 3.3 | 3.6 | 3.4 | C | 57 |
| NOx | FF | 3b | 2.0 | 2.0 | 2.0 | 3.9 | 3.9 | 3.9 | C | 57 |
| NOx | FF | 3b | 1.8 | 3.0 | 2.3 | 3.6 | 6.0 | 4.5 | C | 57 |
| NOx | FF | 3b | 0.80 | 0.90 | 0.85 | 1.6 | 1.8 | 1.7 | C | 57 |
| NOx | FF | 3b | 2.7 | 2.7 | 2.7 | 5.3 | 5.4 | 5.3 | C | 57 |
| NOx | FF | 3b | 2.4 | 3.2 | 2.8 | 4.7 | 6.3 | 5.5 | C | 57 |
| NOx | FF | 6c | 0.013 | 0.045 | 0.026 | 0.026 | 0.090 | 0.051 | B | 61 |
| NOx | FF | 3c | 3.4 | 3.8 | 3.6 | 6.8 | 7.5 | 7.1 | B | 62 |

TABLE 4-5. (continued)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| NOx | FF | 3c | 2.6 | 3.4 | 3.1 | 5.3 | 6.8 | 6.1 | B | 63 |
| NOx | FF | 3 | 3.0 | 3.1 | 3.1 | 6.0 | 6.3 | 6.1 | B | 64 |
| NOx | FF | 3d | 0.0030 | 0.0032 | 0.0031 | 0.0060 | 0.0063 | 0.0061 | D | 56 |
| NOx | FF | 2d | 4.6 | 4.9 | 4.8 | 9.2 | 9.7 | 9.5 | C | 60 |
| CO | ESP | 3 | 1.0 | 1.2 | 1.1 | 2.0 | 2.4 | 2.2 | B | 31 |
| CO | ESP | 1 | NA | NA | 0.32 | NA | NA | 0.63 | NR | 65 |
| CO | FF | 3a | 0.52 | 0.64 | 0.58 | 1.0 | 1.3 | 1.2 | C | 21 |
| CO | FF | 3a | 0.60 | 0.65 | 0.62 | 1.2 | 1.3 | 1.2 | B | 24 |
| CO | FF | 3b | 0.24 | 0.33 | 0.30 | 0.48 | 0.66 | 0.59 | C | 57 |
| CO | FF | 3b | 0.55 | 1.1 | 0.85 | 1.1 | 2.1 | 1.7 | C | 57 |
| CO | FF | 3b | 0.46 | 0.60 | 0.55 | 0.92 | 1.2 | 1.1 | C | 57 |
| CO | FF | 3b | 0.26 | 0.34 | 0.29 | 0.51 | 0.67 | 0.57 | C | 57 |
| CO | FF | 6c | 0.47 | 1.62 | 0.85 | 0.94 | 3.2 | 1.7 | B | 61 |
| CO | FF | 3c | 0.20 | 0.38 | 0.26 | 0.39 | 0.76 | 0.52 | B | 62 |
| CO | FF | 3c | 1.4 | 1.6 | 1.5 | 2.7 | 3.2 | 3.1 | B | 63 |
| CO | FF | 3 | 2.0 | 2.5 | 2.1 | 3.9 | 4.9 | 4.3 | C | 64 |
| CO | FF | 3 | 3.5 | 5.5 | 4.4 | 6.9 | 11 | 8.7 | A | 76 |
| CO2 | ESP | 3 | 800 | 850 | 800 | 1,600 | 1,700 | 1,600 | B | 31 |
| CO2 | ESP | 1 | NA | NA | 500 | NA | NA | 1,000 | NR | 65 |
| CO2 | FF | 3a | 900 | 950 | 900 | 1,800 | 1,900 | 1,800 | C | 21 |
| CO2 | FF | 3a | 900 | 1,000 | 950 | 1,800 | 2,000 | 1,900 | B | 24 |
| CO2 | FF | 3a | 950 | 950 | 950 | 1,900 | 1,900 | 1,900 | B | 27 |
| CO2 | FF | 3c | 800 | 900 | 850 | 1,600 | 1,800 | 1,700 | B | 61 |
| CO2 | FF | 3c | 950 | 1,000 | 950 | 1,900 | 2,000 | 1,900 | B | 62 |
| CO2 | FF | 3c | 950 | 1,000 | 950 | 1,900 | 2,000 | 1,900 | B | 63 |
| CO2 | FF | 3 | 900 | 900 | 900 | 1,800 | 1,800 | 1,800 | B | 64 |
| CO2 | FF | 3d | 1,050 | 1,400 | 1,200 | 2,100 | 2,800 | 2,400 | D | 56 |
| CO2 | FF | 12d | 1,350 | 1,400 | 1,400 | 2,700 | 2,800 | 2,800 | C | 60 |
| CO2 | FF | 2 | 700 | 950 | 800 | 1,400 | 1,900 | 1,600 | D | 74 |
| CO2 | FF | 6 | 950 | 1,000 | 950 | 1,900 | 2,000 | 1,900 | A | 76 |
| total hyrdocarbons | FF | 3a | 0.048 | 0.094 | 0.064 | 0.10 | 0.19 | 0.13 | B | 24 |
| total hyrdocarbons | FF | 3a | 0.032 | 0.040 | 0.036 | 0.065 | 0.080 | 0.071 | B | 27 |
| total hyrdocarbons | FF | 3b | 0.070 | 0.075 | 0.075 | 0.14 | 0.15 | 0.15 | C | 57 |
| total hyrdocarbons | FF | 3b | 0.0060 | 0.014 | 0.010 | 0.012 | 0.027 | 0.019 | C | 57 |
| total hyrdocarbons | FF | 3b | 0.030 | 0.037 | 0.033 | 0.059 | 0.074 | 0.066 | C | 57 |
| total hyrdocarbons | FF | 3b | 0.044 | 0.080 | 0.060 | 0.088 | 0.16 | 0.12 | C | 57 |
| total hyrdocarbons | FF | 3b | 0.035 | 0.060 | 0.045 | 0.069 | 0.12 | 0.090 | C | 57 |
| total hyrdocarbons | FF | 3b | 0.017 | 0.025 | 0.020 | 0.033 | 0.050 | 0.040 | C | 57 |
| total hyrdocarbons | FF | 3 | 0.036 | 0.085 | 0.054 | 0.071 | 0.17 | 0.11 | B | 61 |
| total hyrdocarbons | FF | 3 | 0.16 | 0.20 | 0.18 | 0.31 | 0.39 | 0.35 | A | 76 |
| sulfate | FF | 3a | 0.0066 | 0.0069 | 0.0068 | 0.013 | 0.014 | 0.014 | B | 24 |
| sulfate | FF | 3a | 1.2E-06 | 2.0E-06 | 1.7E-06 | 2.38E-06 | 3.91E-06 | 3.4E-06 | B | 27 |
| sulfate | FF | 3b | 0.0017 | 0.0031 | 0.0026 | 0.0033 | 0.0062 | 0.0052 | C | 57 |
| sulfate | FF | 3b | 0.0030 | 0.0055 | 0.0044 | 0.0059 | 0.011 | 0.0087 | C | 57 |
| sulfate | FF | 3b | 0.0040 | 0.0055 | 0.0047 | 0.0080 | 0.011 | 0.0094 | C | 57 |
| sulfate | FF | 3b | 0.0008 | 0.0022 | 0.0014 | 0.0016 | 0.0043 | 0.0027 | C | 57 |
| sulfate | FF | 3b | 0.0060 | 0.0065 | 0.0065 | 0.012 | 0.013 | 0.013 | C | 57 |
| sulfate | FF | 3b | 0.0023 | 0.0031 | 0.0026 | 0.0045 | 0.0062 | 0.0051 | C | 57 |
| SO3 | FF | 3 | 0.0020 | 0.0069 | 0.0053 | 0.0041 | 0.0138 | 0.0105 | B | 24 |
| HCl | FF | 3 | 0.13 | 0.14 | 0.14 | 0.26 | 0.29 | 0.27 | B | 64 |
| HCl | FF | 3 | 0.00094 | 0.0016 | 0.0013 | 0.0019 | 0.0032 | 0.0026 | D | 74 |
| HCl | FF | 3 | 0.0024 | 0.0095 | 0.0060 | 0.0048 | 0.019 | 0.012 | A | 76 |
| Cl | FF | 3 | 6.5E-04 | 1.5E-03 | 1.1E-03 | 0.0013 | 0.0029 | 0.0021 | A | 76 |
| NH3 | FF | 3 | 0.0050 | 0.0052 | 0.0051 | 0.010 | 0.010 | 0.010 | D | 64 |

TABLE 4-5. (continued)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Ag | FF | 3 | 3.0E-07 | 3.2E-07 | 3.1E-07 | 5.9E-07 | 6.3E-07 | 6.1E-07 | A | 76 |
| As | FF | 3 | 5.0E-06 | 7.0E-06 | 6.0E-06 | 1.0E-05 | 1.4E-05 | 1.2E-05 | A | 76 |
| Ba | FF | 3 | 0.00011 | 0.00049 | 0.00023 | 0.00021 | 0.00098 | 0.00046 | A | 76 |
| Be | FF | 3 | 1.9E-07 | 5.0E-07 | 3.3E-07 | 3.8E-07 | 9.9E-07 | 6.6E-07 | A | 76 |
| Cd | FF | 3 | 3.7E-06 | 1.5E-05 | 7.9E-06 | 7.3E-06 | 3.1E-05 | 1.6E-05 | D | 74 |
| Cd | FF | 3 | 9.5E-07 | 1.3E-06 | 1.1E-06 | 1.9E-06 | 2.5E-06 | 2.2E-06 | A | 76 |
| Cr | FF | 3 | 4.8E-05 | 0.00011 | 7.0E-05 | 9.6E-05 | 0.00022 | 0.00014 | A | 76 |
| Cu | FF | 3 | 0.00011 | 0.0077 | 0.0026 | 0.00022 | 0.015 | 0.0053 | D | 74 |
| Hg | FF | 3 | 8.5E-05 | 0.00014 | 0.00010 | 0.00017 | 0.00027 | 0.00020 | D | 74 |
| Hg | FF | 3 | 9.0E-06 | 1.3E-05 | 1.0E-05 | 1.8E-05 | 2.5E-05 | 2.0E-05 | A | 76 |
| Pb | FF | 3 | 1.4E-05 | 6.3E-05 | 3.4E-05 | 2.9E-05 | 0.00013 | 6.8E-05 | D | 74 |
| Pb | FF | 3 | 3.5E-05 | 4.0E-05 | 3.8E-05 | 6.9E-05 | 8.0E-05 | 7.5E-05 | A | 76 |
| Se | FF | 3 | 8.5E-05 | 0.00013 | 0.00010 | 0.00017 | 0.00026 | 0.00020 | D | 74 |
| Th | FF | 3 | 2.3E-06 | 3.5E-06 | 2.7E-06 | 4.6E-06 | 6.9E-06 | 5.4E-06 | A | 76 |
| Zn | FF | 3 | 0.00020 | 0.00039 | 0.00028 | 0.00041 | 0.00078 | 0.00056 | D | 74 |
| Zn | FF | 3 | 0.00010 | 0.00029 | 0.00017 | 0.00020 | 0.00058 | 0.00034 | A | 76 |
| acenaphthalene | FF | 3 | 5.3E-06 | 0.00015 | 5.9E-05 | 1.1E-05 | 0.00031 | 0.00012 | D | 74 |
| acenaphthene | FF | 1 | NA | NA | 1.0E-05 | NA | NA | 2.0E-05 | NR | 74 |
| acetone | ESP | 1 | NA | NA | 2.5E-05 | NA | NA | 4.9E-05 | NR | 65 |
| anthracene | FF | 1 | NA | NA | 6.5E-06 | NA | NA | 1.3E-05 | NR | 74 |
| benzene | FF | 3 | 0.0057 | 0.0094 | 0.0080 | 0.011 | 0.019 | 0.016 | D | 74 |
| benzene | ESP | 1 | NA | NA | 0.00043 | NA | NA | 0.00086 | NR | 65 |
| benzo(a)anthracene | FF | 3 | 2.0E-08 | 2.5E-08 | 2.1E-08 | 3.9E-08 | 4.9E-08 | 4.3E-08 | D | 74 |
| benzo(a)pyrene | FF | 3 | 4.9E-08 | 8.5E-08 | 6.5E-08 | 9.9E-08 | 1.7E-07 | 1.3E-07 | D | 74 |
| benzo(b)fluoranthene | FF | 3 | 6.5E-08 | 6.6E-07 | 2.8E-07 | 1.3E-07 | 1.3E-06 | 5.6E-07 | D | 74 |
| benzo(g,h,i)perylene | FF | 3 | 2.5E-08 | 4.7E-08 | 3.9E-08 | 4.9E-08 | 9.4E-08 | 7.8E-08 | D | 74 |
| benzo(k)fluoranthene | FF | 3 | 6.3E-08 | 9.4E-08 | 7.7E-08 | 1.3E-07 | 1.9E-07 | 1.5E-07 | D | 74 |
| bis(2-ethylhexyl)phthalate | ESP | 1 | NA | NA | 0.00011 | NA | NA | 0.00021 | NR | 65 |
| chrysene | FF | 3 | 5.4E-08 | 1.0E-07 | 8.1E-08 | 1.1E-07 | 2.0E-07 | 1.6E-07 | D | 74 |
| dibens(a,h)anthracene | FF | 3 | 2.4E-08 | 3.9E-08 | 3.1E-07 | 4.8E-08 | 7.8E-08 | 6.3E-07 | D | 74 |
| 1,1-dichloroethene | ESP | 1 | NA | NA | 8.0E-07 | NA | NA | 1.6E-06 | NR | 65 |
| ethylbenzene | ESP | 1 | NA | NA | 6.5E-05 | NA | NA | 0.00013 | NR | 65 |
| fluoranthene | FF | 3 | 1.7E-06 | 6.5E-06 | 4.4E-06 | 3.4E-06 | 1.3E-05 | 8.8E-06 | D | 74 |
| fluorene | FF | 3 | 1.1E-06 | 1.7E-05 | 9.4E-06 | 2.2E-06 | 3.4E-05 | 1.9E-05 | D | 74 |
| formaldehyde | FF | 3 | 0.00022 | 0.00027 | 0.00023 | 0.00044 | 0.00054 | 0.00046 | D | 74 |
| indeno(1,2,3-cd)pyrene | FF | 3 | 2.4E-08 | 6.3E-08 | 4.3E-08 | 4.8E-08 | 1.3E-07 | 8.7E-08 | D | 74 |
| methylene chloride | ESP | 1 | NA | NA | 0.00023 | NA | NA | 0.00046 | NR | 65 |
| monochlorobenzene | ESP | 1 | NA | NA | 4.7E-06 | NA | NA | 9.4E-06 | NR | 65 |
| naphthalene | FF | 3 | 8.2E-05 | 0.0020 | 0.00085 | 0.00016 | 0.0039 | 0.0017 | D | 74 |
| phenanthrene | FF | 3 | 2.8E-05 | 0.00044 | 0.00020 | 5.6E-05 | 0.00088 | 0.00039 | D | 74 |
| pyrene | FF | 3 | 7.7E-07 | 3.5E-06 | 2.2E-06 | 1.5E-06 | 7.0E-06 | 4.4E-06 | D | 74 |
| tetrachloroethene | ESP | 1 | NA | NA | 2.2E-06 | NA | NA | 4.3E-06 | NR | 65 |
| toluene | ESP | 1 | NA | NA | 0.00041 | NA | NA | 0.00082 | NR | 65 |
| trichloroethene | ESP | 1 | NA | NA | 2.6E-06 | NA | NA | 5.2E-06 | NR | 65 |
| trichlorofluoromethane | ESP | 1 | NA | NA | 3.3E-05 | NA | NA | 6.5E-05 | NR | 65 |
| 1,1,1-trichloroethane | ESP | 1 | NA | NA | 4.0E-07 | NA | NA | 8.0E-07 | NR | 65 |
| total HpCDD | FF | 3 | 1.8E-10 | 2.1E-10 | 2.0E-10 | 3.6E-10 | 4.3E-10 | 3.9E-10 | D | 74 |
| total OCDD | FF | 3 | 8.5E-10 | 1.3E-09 | 1.0E-09 | 1.7E-09 | 2.6E-09 | 2.0E-09 | D | 74 |
| total PCDD | FF | 3 | 1.2E-09 | 1.5E-09 | 1.4E-09 | 2.4E-09 | 3.1E-09 | 2.7E-09 | D | 74 |
| total PCDF | FF | 2 | 1.1E-10 | 1.9E-10 | 1.4E-10 | 2.2E-10 | 3.7E-10 | 2.9E-10 | D | 74 |
| total TCDF | FF | 2 | 1.1E-10 | 1.9E-10 | 1.4E-10 | 2.2E-10 | 3.7E-10 | 2.9E-10 | D | 74 |
| CDD/CDF | ESP | 1 | NA | NA | 1.2E-09 | NA | NA | 2.3E-09 | NR | 65 |
| 1,2,3,4,6,7,8 HpCDD | FF | 3 | 1.1E-10 | 1.1E-10 | 1.1E-10 | 2.2E-10 | 2.2E-10 | 2.2E-10 | D | 74 |

ESP = electrostatic precipitator.

FF = fabric filter.

ST = spray tower.

NA = not applicable.

NR = not rated.

(a) Multiple tests on same kiln indicated by a-d.

(b) Average CEM readings over 3-day period.

TABLE 4-7. (continued)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PRIMARY LIMESTONE CRUSHING | | | | | | | | | | |
| filterable PM | FF | 4 | 0.00040 | 0.00070 | 0.00050 | 0.00079 | 0.0014 | 0.0010 | B | 9 |
| PRIMARY LIMESTONE SCREENING | | | | | | | | | | |
| filterable PM | FF | 4 | 9.0E-05 | 0.00013 | 0.00011 | 0.00018 | 0.00026 | 0.00022 | C | 9 |
| LIMESTONE TRANSFER | | | | | | | | | | |
| filterable PM | FF | 3 | 8.5E-06 | 2.1E-05 | 1.5E-05 | 1.7E-05 | 4.1E-05 | 2.9E-05 | B | 9 |
| SECONDARY LIMESTONE SCREENING AND CRUSHING | | | | | | | | | | |
| filterable PM | FF | 3 | 8.5E-05 | 0.00021 | 0.00016 | 0.00017 | 0.00041 | 0.00031 | B | 9 |

FF = fabric filter.

NA = not applicable.

NR = not rated.

preheater ~~process~~ kilns, dry preheater/precalciner ~~process~~ kilns, clinker coolers, and other processes, respectively. These tables specify the type of pollutant; control device; number of test runs; minimum, maximum, and average emission factors for each test; data rating; and reference number for each set of test data reviewed. No data were available on emissions from semidry process kilns.

↑ There are BIF tests for Louisville, NE

As has been the practice in previous versions of AP-42 Section 8.6, the emission factors for portland cement kilns presented in Tables 4-2 to 4-5 are expressed in units of mass of pollutant emitted in kg (lb) per mass of clinker produced in Mg (ton). Nine of the 56 references from which kiln emission factors were developed provided process rates in terms of clinker production; 25 references provided process rates in terms of both raw material feed and clinker production; and the remaining 22 references provided process rates on the basis of raw material feed. From those references in which both feed and production rates are provided, an average feed-to-production ratio was determined for each type of kiln. These average feed-to-production ratios are as follows: 1.69 for wet process kilns, 1.63 for long dry process kilns, 1.72 for dry preheater process kilns, and 1.70 for dry preheater/precalciner process kilns. These ratios were rounded to 1.6 for long dry process kilns and 1.7 for the other three types of kilns. For the kiln emission factors developed from references for which only feed rates were provided, these ratios were used to convert emission factors from a feed basis to a clinker production basis. Emission factors for processes other than kilns are presented in Tables 4-6 and 4-7 in units of mass of pollutant emitted per mass of material feed.

Particle size data have not been revised from the previous version of AP-42 Section 8.6 because new data were not available, and no problems were found with the methodology and analysis used to develop the particle size data for the previous version of Section 8.6. A detailed discussion of how the particle size data were developed for the section can be found in Reference 79, which is the background report for the October 1986 revision to the PM emission factors for AP-42 Section 8.6. Tables 4-8 and 4-9 summarize the particle size data from Reference 79 for portland cement kilns and clinker coolers, respectively. These particle size data also were used to develop PM-10 emission factors for kilns and clinker coolers.

EPA should "encourage" the industry to develop better particle size data.

4.2.1 Review of Specific Data Sets

Something doesn't look quite right. The feed/product ratio includes dust losses. Wet kilns often have high dust losses because, in part, of the chain system.

## TABLE 4-8. 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 | Dry process | Wet process with ESP | Dry process with FF |
| 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 79.

## TABLE 4-9. 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 | With gravel bed filter |
| 2.5 | 0.54 | 40 |
| 5.0 | 1.5 | 64 |
| 10.0 | 8.6 | 76 |
| 15.0 | 21 | 84 |
| 20.0 | 34 | 89 |

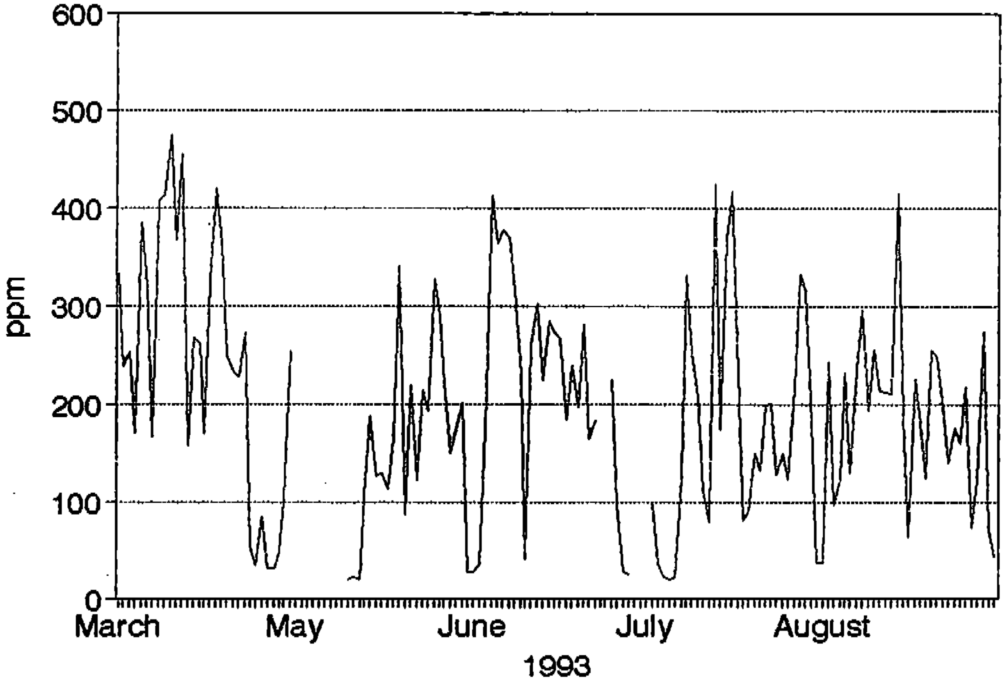
[a] Reference 79.

what about
the predominant
fabric filter?

END OF WRITTEN
COMMENTS BY
WALTER GREER
ASA GROVE

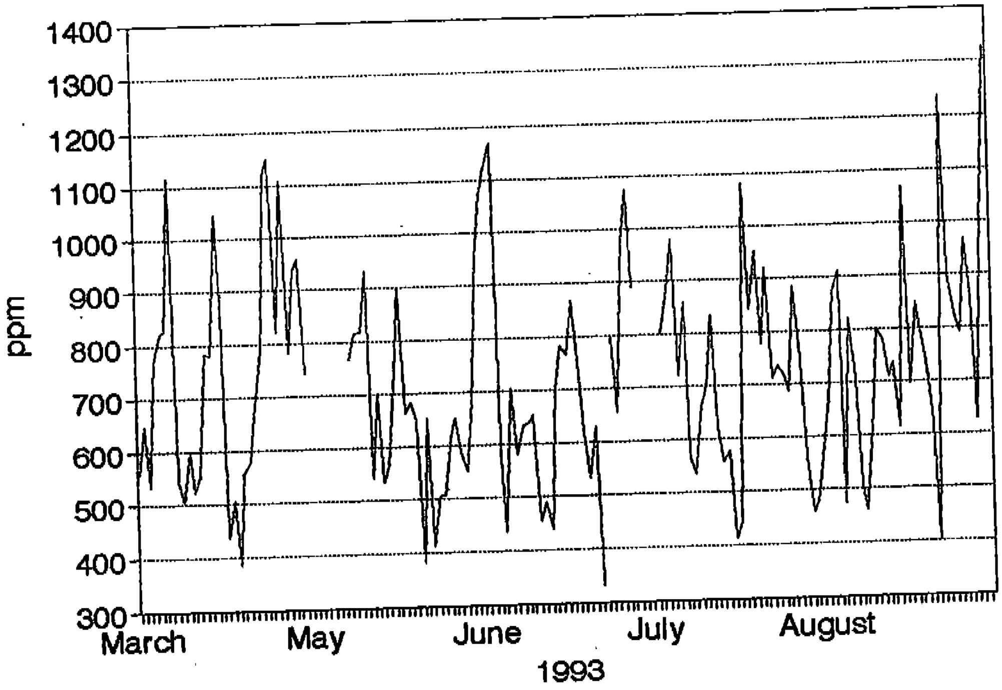
# #1 Kiln CO

Foreman



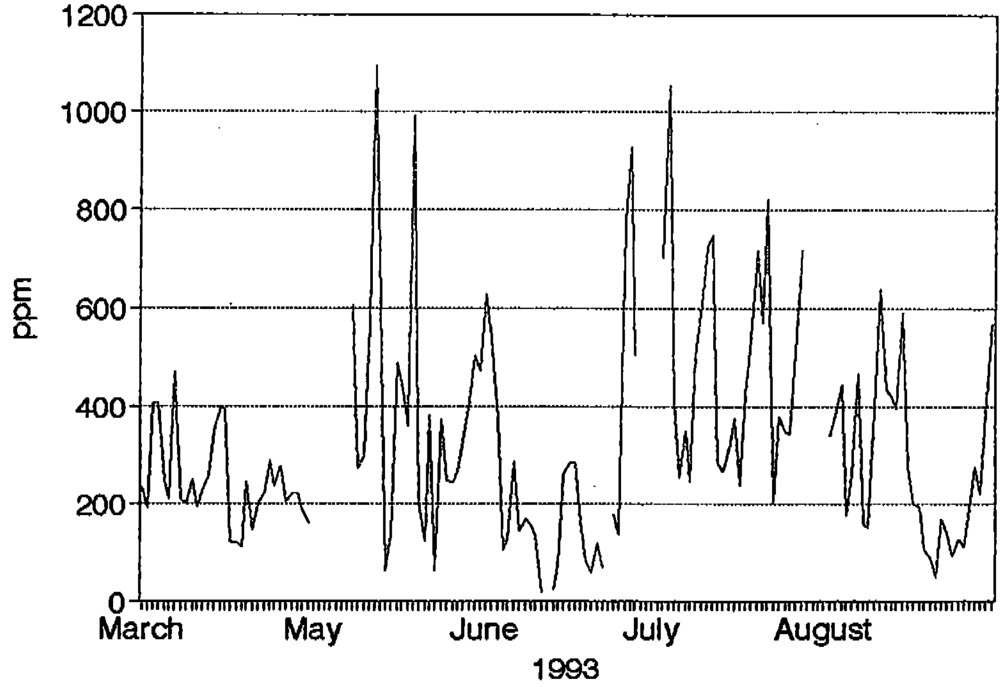
# #1 Kiln NOx

## Foreman



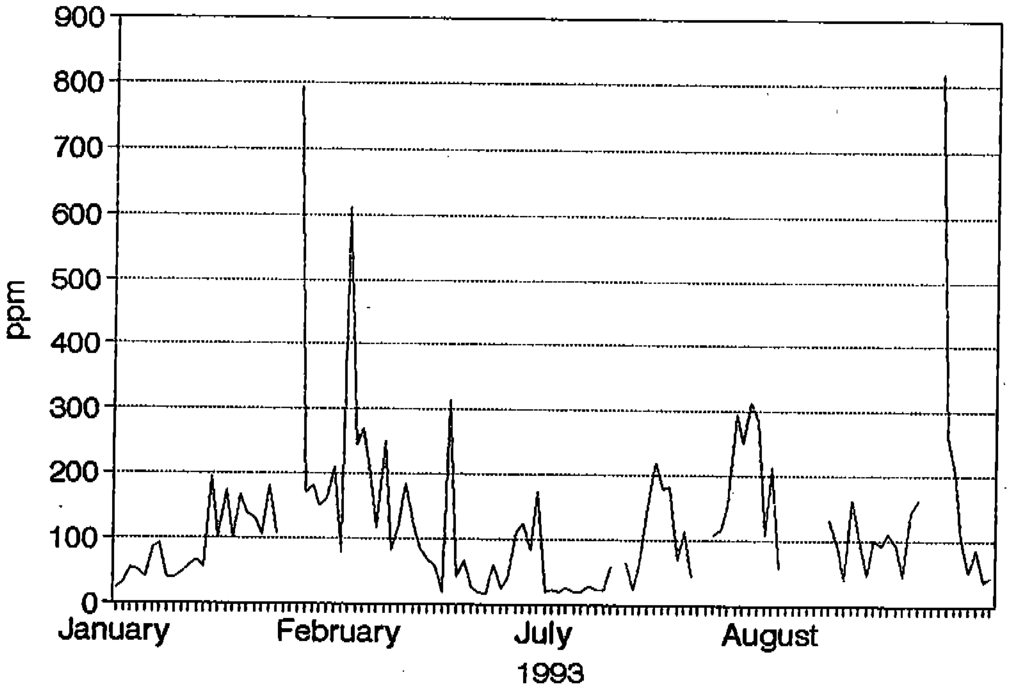
# #1 Kiln SOx

Foreman



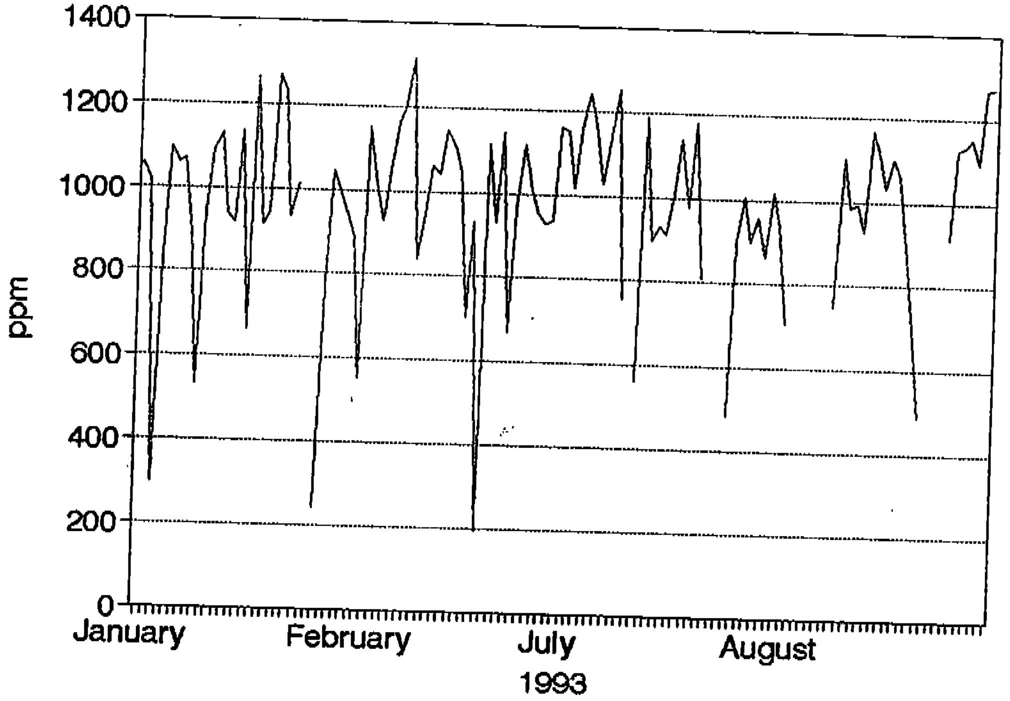
# #2 Kiln CO

Foreman



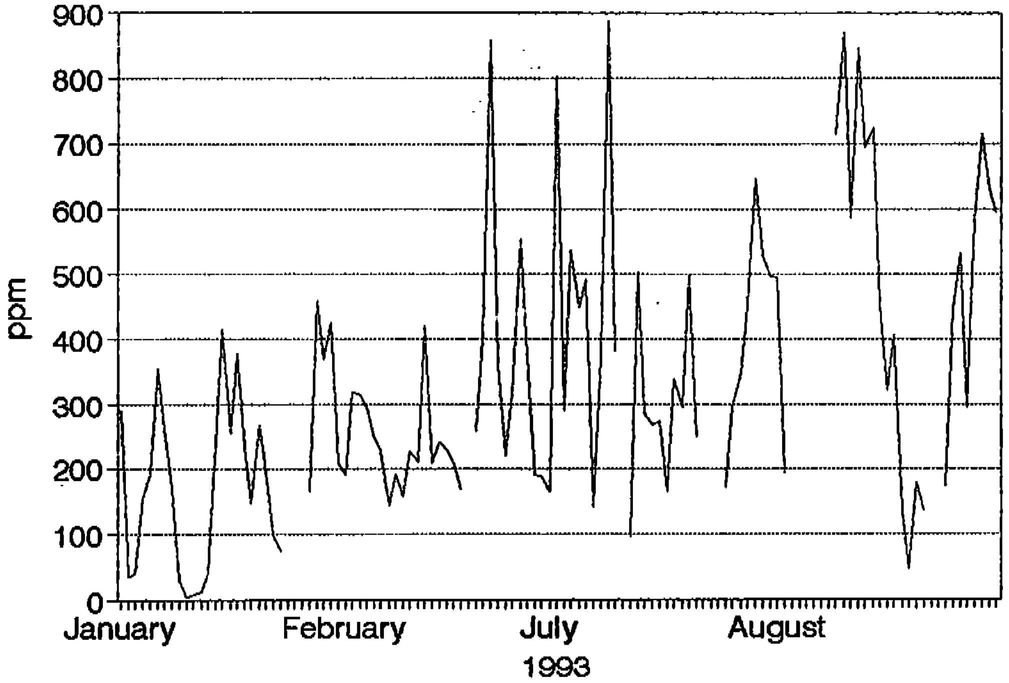
# #2 Kiln NOx

## Foreman



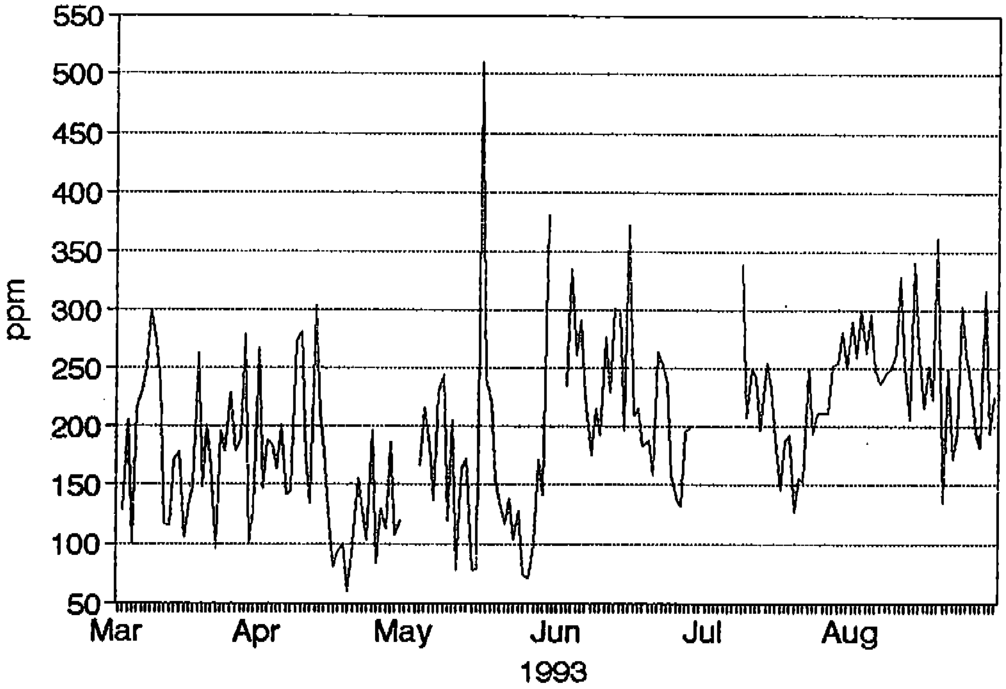
# #2 Kiln SOx

## Foreman



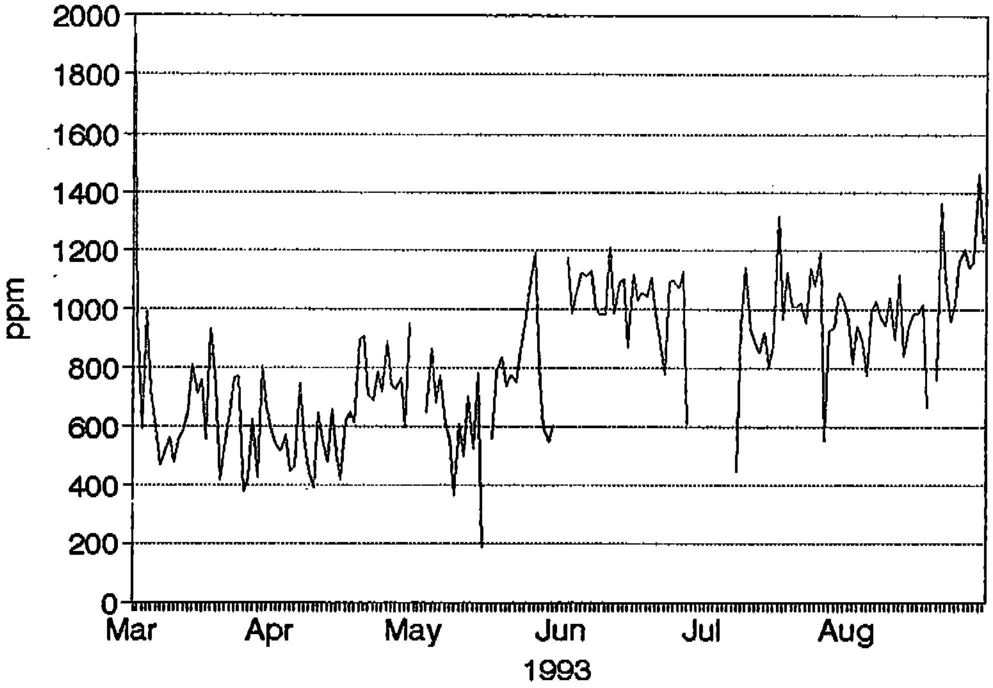
# #3 Kiln CO

Foreman



# #3 Kiln NOx

## Foreman



# #3 Kiln SOx

Foreman