EMISSION FACTOR DOCUMENTATION FOR AP-42 SECTION 11.20 (Formerly 8.25)
Lightweight Aggregate Manufacturing
1. 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 preparation of AP-42 Section 8.25, Lightweight Aggregate Manufacturing.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the lightweight aggregate 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 lightweight aggregate manufacturing. Section 3 is a review of emissions 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 the development of pollutant emission factors for the draft AP-42 section. It includes the review of specific data sets and the results of data analysis. Section 5 presents the AP-42 Section 8.25, Lightweight Aggregate Manufacturing.

2. INDUSTRY DESCRIPTION[1,2]

Lightweight aggregate is a type of coarse aggregate that is used in the production of lightweight concrete products such as concrete block, structural concrete, and pavement. The Standard Industrial Classification (SIC) code for lightweight aggregate manufacturing is 3295, which is the code for minerals and earths, ground or otherwise treated. There currently is no Source Classification Code (SCC) for the industry.

Most lightweight aggregate is produced from materials such as clay, shale, or slate. Blast furnace slag, natural pumice, vermiculite, and perlite can be used as substitutes, however. To produce lightweight aggregate, the raw material (excluding pumice) is expanded to about twice the original volume of the raw material. The expanded material has properties similar to natural aggregate but is less dense and therefore yields a lighter concrete product.

2.1 CHARACTERIZATION OF THE INDUSTRY[3,4]

Approximately 51 lightweight aggregate manufacturing plants operate in the United States. Table 2-1 lists the States in which lightweight aggregate manufacturing plants are located. Domestic production of lightweight aggregate in 1990 totaled 3,800,000 Megagrams (Mg) (4,200,000 tons) and was valued at $26 million.

2.2 PROCESS DESCRIPTION[1]

The production of lightweight aggregate begins with mining or quarrying the raw material. The material is crushed with cone crushers, jaw crushers, hammermills, or pugmills, and is screened for size. Oversized material is returned to the crushers, and the material that passes through the screens is transferred to hoppers. From the hoppers, the material is fed to a rotary kiln, which is fired with coal, coke, natural gas, or fuel oil, to temperatures of about 1200°C (2200°F). As the material is heated, it liquefies, and carbonaceous compounds in the material form gas bubbles, which expand the material; in the process, volatile organic compounds (VOC's) are released. From the kiln, the expanded product (clinker) is transferred by conveyor into the clinker cooler, where it is cooled by air, forming a porous material. After cooling, the lightweight aggregate is screened for size; crushed, if necessary; stockpiled; and shipped. Figure 2-1 illustrates the lightweight aggregate manufacturing process.

Although the majority (approximately 90 percent) of plants use rotary kilns, traveling grates are also used to heat the raw material. In addition, a few plants process naturally occurring lightweight aggregate such as pumice.

2.3 EMISSIONS[1]

Emissions from the production of lightweight aggregate consist primarily of particulate matter (PM), which is emitted by the rotary kilns, clinker coolers, and crushing, screening, and material transfer operations. Pollutants emitted as a result of combustion in the rotary kilns include sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), and VOC's. Chromium, lead, and chlorides also are emitted from the kilns. In addition, other metals, including aluminum, copper, manganese, vanadium, and zinc, are emitted in trace amounts by the kilns. However, emission rates for these pollutants have not been quantified. In addition to PM, clinker coolers emit CO_2 and VOC's.

TABLE 2-1. LIGHTWEIGHT AGGREGATE PRODUCTION IN 1990 BY STATE[a]

State	Amount Produced		Total value $
	Mg	Tons	
Alabama and Arkansas	804,084	886,351	9,732,809
California	176,858	194,953	656,295
Florida and Indiana	283,637	312,656	1,752,382
Kansas, Kentucky, and Louisiana	556,594	613,540	1,759,347
Mississippi and Missouri	272,573	300,460	1,569,533
New York and Montana	300,106	330,810	1,876,954
North Carolina	326,587	360,001	3,319,616
Ohio, Oklahoma, and Pennsylvania	284,456	313,559	1,826,995
Texas	472,643	521,000	2,284,427
Utah and Virginia	326,793	360,228	1,635,545

[a]Reference 4. Production totals represent lightweight aggregate produced from clay and shale only.

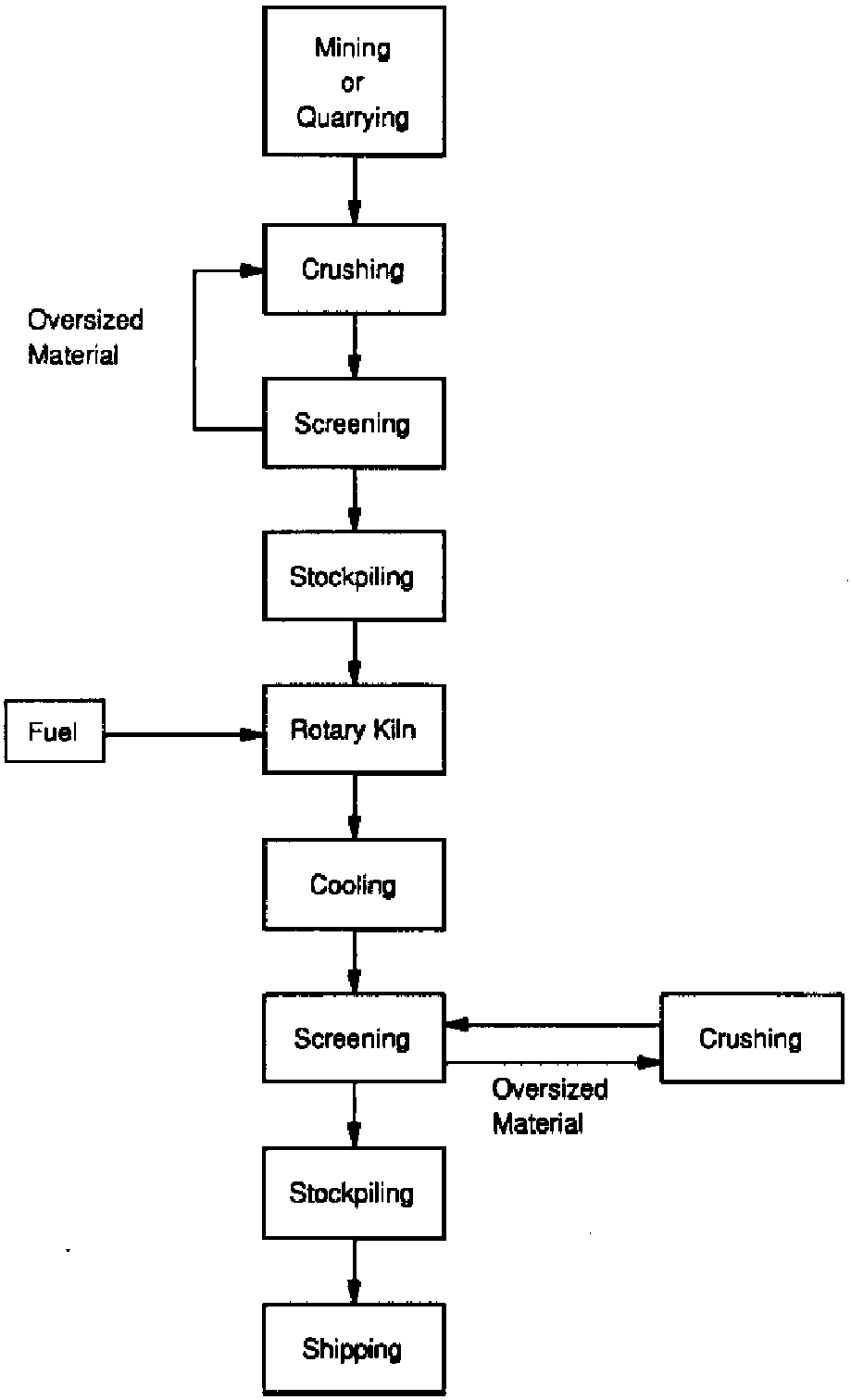

Figure 2-1. Lightweight aggregate manufacturing process flow diagram.

2.4 CONTROL TECHNOLOGY[1]

Emissions from rotary kilns generally are controlled with wet scrubbers. However, fabric filters and electrostatic precipitators (ESP's) are also used to control kiln emissions. Multiclones and settling chambers generally are the only types of controls for clinker cooler emissions. Emissions from crushing, screening and material transfer operations can be controlled by wet suppression or capture/collection systems, but no information is available specifying which controls are used for these operations.

REFERENCES FOR SECTION 2

1. Calciners and Dryers in Mineral Industries-Background Information for Proposed Standards, EPA-450/3-85-025a, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1985.

2. B. H. Spratt, The Structural Use of Lightweight Aggregate Concrete, Cement and Concrete Association, United Kingdom, 1974.

3. 1987 Census of Manufacturers, U. S. Department of Commerce, Washington, D.C., May 1990.

4. R. L. Virta, Annual Report 1990: Clays, Bureau of Mines, U. S. Department of the Interior, Washington, D.C., April 1992.

3. GENERAL DATA REVIEW AND ANALYSIS

3.1 LITERATURE SEARCH AND SCREENING

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 docket for the development of new source performance standards (NSPS) for calciners and dryers in the mineral industries was 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 for identification of the 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 the Minerals Yearbook and Census of Manufacturers. The Aerometric Information Retrieval System (AIRS) data base also was searched for data on the number of plants, plant location, and estimated annual emissions of criteria pollutants.

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 lightweight aggregate manufacturing 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 and information obtained on plant location from the Minerals Yearbook and Census of Manufacturers, 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 lightweight aggregate manufacturing industry. In addition, representative trade associations, including the Expanded Shale, Clay, and Slate Institute and the National Aggregates Association, were contacted for assistance in obtaining information about the industry and emissions.

To reduce the amount of literature collected to a final group of references from which emission factors could 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. 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 half);

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 were 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 on 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. AP-42 SECTION DEVELOPMENT

4.1 DEVELOPMENT OF SECTION NARRATIVE

The AP-42 section described in this report is a new section addressing lightweight aggregate production. The section is based on information gathered from the references cited and includes a description of the industry, a process flow diagram, and emission factors for aggregate drying/expansion and cooling.

4.2 POLLUTANT EMISSION FACTOR DEVELOPMENT

Twenty emission test reports were documented and reviewed in the process of developing the section on lightweight aggregate production. Four of the tests (References 1, 2, 3, and 4), were conducted as part of an emission test program for developing an NSPS for selected processes in the lightweight aggregate industry. These tests were sponsored by EPA. The remaining test reports reviewed were industry-sponsored compliance tests (References 5 to 20). Emission factors could not be developed from two of the test reports (References 10 and 17) due to a lack of process data.

4.2.1 Review of Specific Data Sets

4.2.1.1 Reference 1. This test included measurements of filterable PM, condensible organic and inorganic PM, particle size distribution, sulfur dioxide (SO_2), NO_x, hydrocarbons, and CO_2 from a coal-fired rotary kiln. Also included are measurements of filterable PM, condensible organic and inorganic PM, and particle size distribution for reciprocating grate clinker cooler emissions. Methods 5, 6, 7, and 25 sampling trains were used for the PM, SO_2, NO_x, and total VOC's (TVOC's) measurements, respectively. The condensible PM fractions were determined by means of ether/chloroform extraction. Cascade impactors were used to quantify the particle size distribution. The test was sponsored by EPA as part of an emission test program for developing an NSPS for selected processes in the lightweight aggregate industry.

Emissions from the kiln were controlled by a medium-energy wet scrubber. Three runs were conducted on both the inlet and outlet of the scrubber. The uncontrolled emissions measured at the inlet include filterable PM, condensible organic and inorganic PM, size-specific PM, and SO_2. The controlled emissions measured at the scrubber outlet include filterable PM, condensible organic and inorganic PM, size-specific PM, SO_2, NO_x, and TVOC's.

Emissions from the clinker cooler were controlled by a settling chamber. Three runs were conducted at the clinker cooler exit stack. The controlled emissions measured at the exit stack include filterable PM, condensible organic and inorganic PM, and particle size distribution.

A rating of A was assigned to both the kiln and clinker cooler test data. The reports included adequate detail, the methodology appeared to be sound, and no problems were reported.

4.2.1.2 Reference 2. This test included measurements of filterable PM, condensible organic and inorganic PM, particle size distribution, SO_2, NO_x, and CO_2 from a coal-fired rotary kiln. Also included are measurements of filterable PM, condensible organic and inorganic PM, particle size distribution, and CO_2 from a reciprocating grate clinker cooler. Methods 5, 6, and 7 sampling trains were used for the PM, SO_2, and NO_x measurements, respectively. An ether/chloroform extraction was performed on the impinger contents to quantify the condensible PM fractions. Cascade impactors were

used for quantifying the particle size distribution. In addition, a trace element analysis was performed on the solid residue filtered from the scrubber water. The results of this analysis are presented in Table 4-1. The emission test was sponsored by EPA as part of an emission test program for developing an NSPS for selected processes in the lightweight aggregate industry.

Emissions from the kiln were controlled by a medium-energy wet scrubber. Three runs were conducted on the scrubber inlet. The uncontrolled emissions measured at the inlet include SO_2. Two tests consisting of four and three runs each were conducted at the scrubber outlet. The first scrubber outlet test measured controlled emissions of filterable PM, condensible organic and inorganic PM, and particle size distribution. Problems in three of four test runs at the scrubber outlet invalidated the outlet PM data. The second scrubber outlet test measured controlled emissions of SO_2 and NO_x. Carbon dioxide concentrations were measured at all sampling points.

Emissions from the clinker cooler were controlled by a dry multicyclone. Four runs were conducted at the clinker cooler exit stack. The emissions measured at the exit stack include filterable PM, condensible organic and inorganic PM, particle size distribution, and CO_2.

A rating of A was assigned to both the kiln and clinker cooler test data. The reports included adequate detail, the methodology appeared to be sound, and no problems were reported during the valid test runs.

4.2.1.3 Reference 3. This test included measurements of filterable PM, condensible organic and inorganic PM, particle size distribution, SO_2, NO_x, hydrocarbons, and CO_2 from a coal-fired rotary kiln. Also included are measurements of filterable PM, condensible organic and inorganic PM, particle size distribution, and CO_2 from a reciprocating grate clinker cooler. Methods 5, 6, and 7 sampling trains were used for the PM, SO_2, and NO_x measurements, respectively. The impinger contents were recovered and analyzed for organic and inorganic condensible PM by ether/chloroform extraction. Flame ionization detection was used to measure hydrocarbons. However, because of excess moisture in the rotameter the test was not completed. Cascade impactors were used for quantifying the particle size distribution. The particle size distribution data for the clinker cooler also are not valid due to testing problems. The test was sponsored by EPA as part of an emission test program for developing an NSPS for selected processes in the lightweight aggregate industry.

Emissions from the kiln were controlled by a medium-energy wet scrubber. Three runs were conducted on both the scrubber inlet and outlet. Uncontrolled SO_2 emissions were measured at the inlet. The controlled emissions measured at the scrubber outlet include filterable PM, condensible organic and inorganic PM, particle size distribution, SO_2, and NO_x. Carbon dioxide concentrations were also measured at the outlet.

Emissions from the clinker cooler were controlled by a fabric filter. Three runs were conducted at both the clinker cooler fabric filter inlet and outlet. The uncontrolled emissions measured at the inlet include filterable PM, condensible organic and inorganic PM, and CO_2. The controlled emissions measured at the outlet include filterable PM, condensible organic and inorganic PM, and particle size distribution. Carbon dioxide concentrations were also measured at the outlet. The clinker cooler emission data will not be used at this time, due to inconsistencies in the uncontrolled and controlled PM data.

A rating of B was assigned to the kiln test data. The report lacked sufficient detail, but the methodology appeared to be sound, and no problems were reported during the valid test runs.

TABLE 4-1. SUMMARY OF TRACE ELEMENT ANALYSIS OF SOLID RESIDUE FROM KILN SCRUBBER WATER, [2,a]

Elements	Test No. 1	Test No. 2	Test No. 3
Al	4.9%	4.9%	4.7%
Sb	<8	<8	<8
As	<14	<14	<14
Ba	660	660	660
Be	<0.12	<0.12	<0.12
Bi	<13	<13	<13
B	3.2%	3.2%	3.2%
Cd	1.7	1.5	1.5
Ca	1.2%	1.2%	1.4%
Cr	69	66	54
Co	50	42	37
Au	<8	<8	<8
In	<13	<13	<13
Fe	5.5%	5.1%	5.3%
Pb	65	60	63
Li	68	72	65
Mg	5,900	5,800	4,900
Mn	350	290	360
Hg	<8	<8	<8
Mo	21	27	26
Ni	420	401	360
P	480	420	460
Pt	<8	<8	<8
K	1.5%	1.5%	1.3%
Se	<20	<20	<20
Ag	<0.5	<0.5	<0.5
Na	4.2%	4.4%	4.3%
Sr	80	83	80
Te	<25	<25	<25
Tl	<25	<25	<25
Sn	<50	<50	<50
Ti	3,900	3,900	3,300
U	<15	<15	<15
V	160	140	137
W	<8	<8	<8
Y	3.3	1.8	2.3
Zn	180	150	130

[a]All concentrations in ppm unless otherwise indicated.

4.2.1.4 Reference 4. This test included measurements of filterable PM, condensible organic and inorganic PM, particle size distribution, SO_2, NO_x, hydrocarbons, and CO_2 from a coal-fired rotary kiln. Also included are measurements of filterable PM, condensible organic and inorganic PM, and particle size distribution from a reciprocating grate clinker cooler. Methods 5, 6, 7, and 25 sampling trains were used for the PM, SO_2, NO_x, and hydrocarbon measurements, respectively. An ether/chloroform extraction was used to quantify the condensible PM fractions. Cascade impactors were used for quantifying the particle size distribution. A trace element analysis was performed on the PM captured in the clinker cooler settling chamber. The results are presented in Table 4-2. The test was sponsored by EPA as part of an emission test program for developing an NSPS for selected processes in the lightweight aggregate industry.

Because of a failed post-test leak check and loss of sample, not all tests at the rotary kiln scrubber inlet and outlet are valid. Problems are documented at the inlet test locations, as well as at the scrubber outlet.

Emissions from the clinker cooler were controlled by a baffled settling chamber. Three runs were conducted at the clinker cooler stack exit. The controlled emissions measured at the stack exit include filterable PM, condensible organic and inorganic PM, and particle size distribution.

A rating of D was assigned to the kiln test data. The test had documented problems and therefore will not be used to develop emission factors. A rating of A was assigned to the clinker cooler test data. The test description included adequate detail, the methodology appeared to be sound, and no problems were reported.

4.2.1.5 Reference 5. This test included measurements of filterable PM, chromium, lead, and chlorides from a liquid waste-fired rotary kiln. A Method 5 sampling train was used for the PM measurements. Chromium and lead concentrations in the PM sample were determined using atomic absorption, and the chlorides in the impingers were analyzed by the Argentometric Method. The test was sponsored by Carolina Solite Corporation to satisfy Provisos 10 and 11 of permit No. 3225R4, issued by the North Carolina Department of Natural Resources and Community Development.

Emissions from the kiln were controlled by an unspecified system. Three runs were conducted on both the control system inlet and outlet. Filterable PM was measured at the inlet and outlet of the control system and was analyzed for chromium, lead, and chloride concentrations. The first run on the inlet was not completed due to darkness and overheating of the sampling equipment. No information was provided on the chemical composition of the waste fuel.

A rating of B was assigned to the inlet test data. The test description lacked sufficient detail, but the methodology appeared to be sound, and no problems were reported during the valid runs. A rating of D was assigned to the outlet test data because the control system was not specified. The outlet data were not used to develop emission factors for AP-42.

4.2.1.6 Reference 6. This test measured SO_2 emissions from a coal-fired rotary kiln. A Method 8 sampling train was used. The test was sponsored by Carolina Solite Corporation to determine compliance with the SO_2 emission-limiting standard of the air permit for the kiln.

Emissions from the kiln were controlled by an unspecified type of scrubber. Three runs were conducted on the scrubber inlet to measure uncontrolled SO_2 emissions.

TABLE 4-2. SUMMARY OF TRACE ELEMENT ANALYSIS OF CLINKER COOLER SETTLING CHAMBER CATCH [4]

Elements	Captured particulate matter[a]		
	Test No. 1	Test No. 2	Test No. 3
Al	8.1	8.3	7.9
Sb	<7.1	<7.5	<7.5
As	26	25	24
Ba	680	660	630
Be	<0.13	<0.13	<0.13
Bi	<13	<13	<13
B	<2.2	<2.2	<2.2
Cd	3.7	3.7	3.5
Ca	5.7	5.3	7.4
Cr	78	79	75
Co	20	19	19
Cu	36	34	34
Au	<7.5	<7.5	<7.5
In	<13	<13	<13
Fe	4.6	4.5	4.4
Pb	100	120	100
Li	64	62	59
Mg	1.8	1.8	1.7
Mn	520	500	620
Hg	<8	<8	<8
Mo	<0.49	<0.50	<0.50
Ni	40	42	41
P	270	270	270
Pt	<7.5	<7.5	<7.5
K	3.0	3.0	2.9
Se	<20	<20	<20
Si	26	28	28
Ag	<0.49	<0.50	<0.49
Na	1.0	9,700	9,100
Sr	300	280	380
S	4,100	3,400	6,300
Te	<25	<25	<25
Tl	<23	<23	<23
Sm	290	300	280
Ti	4,600	4,500	4,300
U	<15	<15	<15
V	160	160	160
W	<7.5	<7.5	<7.5
Y	21	21	22
Zn	150	140	130

[a]All concentrations in ppm.

A rating of B was assigned to the test data. The test description lacked sufficient detail, but the methodology appeared to be sound, and no problems were reported.

4.2.1.7 Reference 7. This test measured SO_2 emissions from the same rotary kiln as reported in Reference 6. A Method 8 sampling train was used. The test was sponsored by Carolina Solite Corporation to determine compliance with the SO_2 emission-limiting standard of the air permit for the kiln.

Emissions from the kiln were controlled by an unspecified type of scrubber. Three runs were conducted on the scrubber outlet to measure controlled SO_2 emissions.

A rating of B was assigned to the test data. The test description lacked sufficient detail, but the methodology appeared to be sound, and no problems were reported.

4.2.1.8 Reference 8. This reference documents measurements of controlled filterable PM emissions from a coke-fired lightweight aggregate kiln. The test was sponsored by Florida Solite Corporation to demonstrate compliance with State regulations. Emissions from the kiln are controlled by means of a mechanical collector and wet scrubber in series. A total of three test runs were conducted using EPA Method 5 (front half).

A rating of B was assigned to the data. The test methodology was sound, and no problems were reported. However, the report lacked detailed descriptions of the process and control device and included overall average process rates rather than on a run-by-run basis.

4.2.1.9 Reference 9. This reference documents measurements of controlled filterable PM, SO_2, and CO_2 emissions from a gas-fired lightweight aggregate kiln. The test was sponsored by Chandler Materials Company to demonstrate compliance with State regulations. Emissions from the kiln are controlled by means of a wet scrubber.

A rating of D was assigned to the data. The test methods are not specified in the report, the report does not include a process description, and information on the control device is not provided.

4.2.1.10 Reference 11. This reference documents measurements of controlled filterable PM emissions from the same coke-fired lightweight aggregate kiln as was tested in Reference 8. The test was sponsored by Florida Solite Corporation to demonstrate compliance with State regulations. Emissions from the kiln are controlled by means of mechanical collector and wet scrubber in series. A total of three test runs were conducted using EPA Method 5 (front half).

A rating of B was assigned to the data. The test methodology was sound, and no problems were reported. However, the report lacked detailed descriptions of the process and control device and included overall average process rates rather than on a run-by-run basis.

4.2.1.11 Reference 12. This reference documents measurements of controlled filterable PM and uncontrolled CO_2 emissions from a coal-fired rotary lightweight aggregate kiln (kiln No. 1). The test was sponsored by Tombigbee Lightweight Aggregate Corporation to demonstrate compliance with State regulations. Emissions from the kiln are controlled by means of a wet scrubber, which operated at a pressure drop of 3.5 kilopascals (kPa) (14-inch water column [in. w.c.]). A total of three test runs

were conducted. The PM emissions were quantified using Method 5 (front half), and the CO_2 emissions were measured by Orsat analysis.

A rating of B was assigned to the data. The test methodology was sound, and no problems were reported. However, the report lacked detailed descriptions of the process and control device and included overall average process rates rather than on a run-by-run basis.

4.2.1.12 Reference 13. This reference documents measurements of controlled filterable PM and uncontrolled CO_2 emissions from another (kiln No. 2) coal-fired rotary lightweight aggregate kiln at the facility tested in Reference 12. The test was sponsored by Tombigbee Lightweight Aggregate Corporation to demonstrate compliance with State regulations. Emissions from the kiln are controlled by means of a wet scrubber, which operated at a pressure drop of 3.5 kPa (14-in. w.c.). A total of three test runs were conducted. The PM emissions were quantified using Method 5 (front half), and the CO_2 emissions were measured by Orsat analysis.

A rating of B was assigned to the data. The test methodology was sound, and no problems were reported. However, the report lacked detailed descriptions of the process and control device and included overall average process rates rather than on a run-by-run basis.

4.2.1.13 Reference 14. This reference documents measurements of uncontrolled and controlled filterable PM emissions and uncontrolled CO_2 emissions from a coal-fired lightweight aggregate kiln. The test was sponsored by Carolina Stalite Corporation to demonstrate compliance with State regulations. Emissions from the kiln are controlled by means of a fabric filter. The stack gas temperature at the fabric filter outlet ranged from 76° to 83°C (169° to 181°F). A total of three test runs were conducted. The PM emissions were quantified using Method 5 (front half), and the CO_2 emissions were measured by Orsat analysis.

A rating of B was assigned to the data. The test methodology was sound, and no problems were reported. However, the report lacked detailed descriptions of the process and control device and included overall average process rates rather than on a run-by-run basis.

4.2.1.14 Reference 15. This reference documents measurements of controlled filterable PM emissions and uncontrolled CO_2 emissions from a lightweight aggregate kiln (kiln No. 2), which is fired with coal and No. 2 fuel oil. The test was sponsored by Lehigh Portland Cement Company to demonstrate compliance with State regulations. Emissions from the kiln are controlled by means of an ESP. The ESP has two fields, which operated at 132 and 155 volts (V), and 170 and 191 milliamps direct current (mA-DC), respectively. A total of three test runs were conducted. The PM emissions were measured using State of Maryland Method 1005. This method is identical to EPA Method 5 except that the method requires a minimum sample volume of 1.42 cubic meters (m^3) (50 cubic feet [ft^3]) and minimum sampling times of 3 minutes at each traverse point. The CO_2 emissions were quantified by fyrite.

A rating of B was assigned to the PM emission data. The test methodology was sound, and no problems were reported. However, the report lacked detailed descriptions of the process and control device and included overall average process rates rather than on a run-by-run basis. The CO_2 data are rated C due to the relative inaccuracy of the fyrite method.

4.2.1.15 Reference 16. This reference documents measurements of controlled filterable PM emissions from another lightweight aggregate kiln (kiln No. 1) at the facility tested in Reference 15.

This kiln also is fired with coal and No. 2 fuel oil. The test was sponsored by Lehigh Portland Cement Company to demonstrate compliance with State regulations. Emissions from the kiln are controlled by means of an ESP. The ESP has two fields, which operated at 164 and 215 V and 123 and 157 mA-DC, respectively. A total of three test runs were conducted. The PM emissions were measured using State of Maryland Method 1005. This method is identical to EPA Method 5 except that the method requires a minimum sample volume of 1.42 m^3 (50 ft^3) and minimum sampling times of 3 minutes at each traverse point. The CO_2 emissions were quantified by fyrite.

A rating of B was assigned to the PM emissions data. The test methodology was sound, and no problems were reported. However, the report lacked detailed descriptions of the process and control device and included overall average process rates rather than on a run-by-run basis. The CO_2 data are rated C due to the relative inaccuracy of the fyrite method.

Reference 18 . This report documents measurements of filterable PM, hydrogen chloride (HCl), chlorine, hexavalent chromium (Cr^{+6}), several metals, and CO_2 from two rotary kilns (kiln Nos. 2 and 4) that were fired with liquid hazardous waste. The purpose of the emission test was to demonstrate compliance with regulations promulgated under the authority of the Resource Conservation and Recovery Act (RCRA) in 40 CFR 266.104(b) through 266.107. The test was conducted in 1992. Process rates were provided on the basis of raw material feed. Emissions from each of the kilns are controlled with a fabric filters.

Particulate matter emissions were measured using Method 5, HCl and chlorine emissions were measured using Method 0050, Method 0012 was used to quantify metals emissions, and Cr^{+6} emissions were measured using Method 0013. Continuous emission monitors (CEM's) were used to measure CO (Method 10), total hydrocarbons (Method 25A), and CO_2 (Method 3A) emissions. Three PM, HCl/chlorine, metals, and Cr^{+6} runs were conducted. Hourly rolling averages of the CO, total hydrocarbons, and CO_2 emissions were recorded, and the average emission rates for each test run were reported. In addition, samples of the raw feed material, finished product, fabric filter dust, and hazardous waste feed material were analyzed for total chlorides and 10 metals. The average concentrations of these chemical constituents are summarized in Table 4-3.

Emission factors were developed for emissions of filterable PM, HCl, chlorine, CO, CO_2, total hydrocarbons, and 10 metals from each of the two kilns. For some of the metals runs, the concentrations of specific metals (sampling train front half, back half, or both) were below detection limit. In such cases, the emission factor is based on an assumed concentration of one-half the detection limit for the specific metal. However, for Cr^{+6} emissions, both front and back halves of all runs were below detection limit, and a Cr^{+6} emission factor was not developed. The emission data are summarized in Table 4-4.

The emission data for filterable PM, HCl, chlorine, CO_2, and total hydrocarbons are rated B. The test methodologies were sound and no problems were reported, but the report lacked adequate documentation for a higher rating.

For kiln No. 2, the emission data for arsenic, barium, cadmium, total chromium, lead, and mercury are rated B; the emission data for antimony are rated C; and the emission data for beryllium, silver, and thallium are rated D. For kiln No. 4, the emission data for antimony, arsenic, cadmium, lead, and mercury are rated B; the emission data for barium and total chromium are rated C; and the

TABLE 4-3. SUMMARY OF SAMPLE ANALYSIS FOR REFERENCE 18 PLANT

Kiln No.	Pollutant	Average concentration, ppm by weight[a]			
		Raw feed	Product	Fabric filter dust	Waste fuel
2	Total chloride	< 0.04	< 0.04	NA	1.13
	Antimony	< 0.39	< 0.39	< 0.39	2.74
	Arsenic	6.08	4.44	20.6	1.24
	Barium	106.3	229	157	146
	Beryllium	2.12	2.18	8.12	< 0.07
	Cadmium	< 0.45	< 0.45	24.8	3.2
	Total chromium	91.7	67.2	62.3	21.8
	Lead	< 8.3	15.2	624	135
	Mercury	< 0.04	< 0.04	< 0.07	0.31
	Silver	< 0.7	< 0.7	< 0.7	< 0.7
	Thallium	1.55	1.42	1.87	< 0.4
4	Total chloride	< 0.04	< 0.04	NA	2.37
	Antimony	< 0.39	< 0.39	< 0.39	3.05
	Arsenic	4.37	5.33	82.7	< 2.61
	Barium	108.4	195	142	69.1
	Beryllium	2.32	4.43	8.9	< 0.07
	Cadmium	< 0.45	< 0.45	184	< 0.45
	Total chromium	99.1	49.4	68.3	7.76
	Lead	< 2.1	< 21.6	1,890	26.2
	Mercury	< 0.04	< 0.04	0.11	0.15
	Silver	< 0.7	< 0.7	< 0.7	< 0.7
	Thallium	1.52	1.36	2.75	< 0.4

[a]Concentrations below detection limit are indicated with < symbol.

TABLE 4-4. SUMMARY OF TEST DATA FOR REFERENCE 18 PLANT[a]

Kiln No.	Pollutant	No. of runs	Emission factor, kg/Mg			Emission factor, lb/ton			Data rating
			Minimum	Maximum	Average	Minimum	Maximum	Average	
2	Filterable PM	3	0.012	0.017	0.014	0.023	0.035	0.029	B
	Hydrogen chloride	3	2.0	2.5	2.2	4.0	5.0	4.4	B
	Chlorine	3	0.013	0.11	0.051	0.026	0.23	0.10	B
	CO_2	9	259	320	291	517	641	582	B
4	Filterable PM	3	0.015	0.053	0.029	0.029	0.11	0.059	B
	Hydrogen chloride	3	2.1	2.7	2.5	4.2	5.4	4.9	B
	Chlorine	3	0.00071	0.10	0.044	0.0014	0.20	0.088	B
	CO_2	9	315	394	348	629	787	695	B
2	Antimony	3	2.2×10^{-6}	7.0×10^{-6}	4.5×10^{-6}	4.5×10^{-6}	1.4×10^{-5}	8.9×10^{-6}	C
	Arsenic	3	4.7×10^{-6}	1.4×10^{-5}	9.0×10^{-6}	9.4×10^{-6}	2.7×10^{-5}	1.8×10^{-5}	B
	Barium	3	2.8×10^{-5}	6.0×10^{-5}	4.4×10^{-5}	5.6×10^{-5}	1.2×10^{-4}	8.8×10^{-5}	B
	Beryllium	3	1.5×10^{-6}	2.5×10^{-6}	1.8×10^{-6}	2.9×10^{-6}	5.1×10^{-6}	3.7×10^{-6}	D
	Cadmium	3	2.1×10^{-5}	0.00047	0.00022	4.2×10^{-5}	0.00093	0.00044	B
	Chromium	3	2.8×10^{-5}	3.6×10^{-5}	3.2×10^{-5}	5.5×10^{-5}	7.3×10^{-5}	6.3×10^{-5}	B
	Lead	3	0.00020	0.00060	0.00039	0.00041	0.0012	0.00078	B
	Mercury	3	1.3×10^{-5}	2.3×10^{-5}	1.8×10^{-5}	2.7×10^{-5}	4.6×10^{-5}	3.5×10^{-5}	B
	Silver	3	3.1×10^{-6}	9.5×10^{-5}	3.4×10^{-5}	6.1×10^{-6}	0.000191	6.8×10^{-5}	D
	Thallium	3	5.9×10^{-7}	3.2×10^{-6}	1.7×10^{-6}	1.2×10^{-6}	6.4×10^{-6}	3.4×10^{-6}	D
	CO	3	0.26	0.37	0.30	0.52	0.75	0.61	B
	Total hydrocarbons[b]	3	0.013	0.016	0.014	0.026	0.032	0.028	B

TABLE 4-4. (continued)

Kiln No.	Pollutant	No. of runs	Emission factor, kg/Mg			Emission factor, lb/ton			Data rating
			Minimum	Maximum	Average	Minimum	Maximum	Average	
4	Antimony	3	5.1×10^{-6}	6.1×10^{-6}	5.5×10^{-6}	1.0×10^{-5}	1.2×10^{-5}	1.1×10^{-5}	B
	Arsenic	3	5.8×10^{-6}	1.4×10^{-5}	8.6×10^{-6}	1.2×10^{-5}	2.8×10^{-5}	1.7×10^{-5}	B
	Barium	3	1.3×10^{-5}	4.4×10^{-5}	3.1×10^{-5}	2.6×10^{-5}	8.8×10^{-5}	6.1×10^{-5}	C
	Beryllium	3	7.1×10^{-7}	2.8×10^{-6}	1.4×10^{-6}	1.4×10^{-6}	5.6×10^{-6}	2.8×10^{-6}	D
	Cadmium	3	1.5×10^{-5}	0.000118	7.2×10^{-5}	2.9×10^{-5}	0.000235	0.000145	B
	Chromium	3	1.3×10^{-5}	5.1×10^{-5}	3.3×10^{-5}	2.5×10^{-5}	0.00010	6.6×10^{-5}	C
	Lead	3	0.000138	0.000753	0.000494	0.000276	0.0015	0.000988	B
	Mercury	3	1.0×10^{-5}	1.3×10^{-5}	1.2×10^{-5}	2.1×10^{-5}	2.6×10^{-5}	2.3×10^{-5}	B
	Silver	3	4.7×10^{-6}	6.9×10^{-6}	5.5×10^{-6}	9.3×10^{-6}	1.4×10^{-5}	1.1×10^{-5}	D
	Thallium	3	7.1×10^{-7}	2.3×10^{-6}	1.4×10^{-6}	1.4×10^{-6}	4.5×10^{-6}	2.9×10^{-6}	D
	CO	3	0.29	0.62	0.41	0.59	1.2	0.82	B
	Total hydrocarbons[b]	3	0.003798	0.013	0.0083	0.0076	0.026	0.017	B

[a]Emission factors in units of raw material feed rate.
[b]Total hydrocarbons as methane.

emission data for beryllium, silver, and thallium are rated D. The test methodologies for the metal emission tests were sound, and no problems were reported. The data were downrated from B to C if, for at least one run, either the front or the back half sample was below the detection limit but the error associated with the undetected samples was no more than approximately 30 percent for any run; the data were downrated from B to D if both the front and back half samples were below the detection limit for one or two runs, or the error associated with the undetected samples was more than approximately 30 percent.

Reference 19. This report documents measurements of filterable PM, HCl, chlorine, Cr^{+6}, several metals, and CO_2 from a rotary kiln that were fired with liquid hazardous waste. The purpose of the emission test was to demonstrate compliance with regulations promulgated under the authority of RCRA in 40 CFR 266.104(b) through 266.107. The test was conducted in 1992. Process rates were provided on the basis of raw material feed. Emissions from the kiln are controlled with a fabric filter.

Particulate matter emissions were measured using Method 5, HCl and chlorine emissions were measured using Method 0050, Method 0012 was used to quantify metals emissions, and Cr^{+6} emissions were measured using Method 0013. Continuous emission monitors were used to measure CO (Method 10), total hydrocarbons (Method 25A), and CO_2 (Method 3A) emissions. Three PM, HCl/chlorine, metals, and Cr^{+6} runs were conducted. Hourly rolling averages of the CO, total hydrocarbons, and CO_2 emissions were recorded, and the average emission rates for each test run were reported. In addition, samples of the raw feed material, finished product, fabric filter dust, and hazardous waste feed material were analyzed for total chlorides and 10 metals. The average concentrations of these chemical constituents are summarized in Table 4-5.

Emission factors were developed for emissions of filterable PM, HCl, chlorine, CO, CO_2, total hydrocarbons, and 15 metals from the kiln. For some of the metals runs, the concentrations of specific metals (sampling train front half, back half, or both) were below the detection limit. In such cases, the emission factor is based on an assumed concentration of one-half the detection limit for the specific metal. However, for Cr^{+6} emissions, both front and back halves of all runs were below the detection limit, and a Cr^{+6} emission factor was not developed. The emission data are summarized in Table 4-6.

All emission data from this reference are rated B. The test methodologies were sound and no problems were reported, but the report lacked adequate documentation for a higher rating.

Reference 20. This report documents measurements of filterable PM, HCl, chlorine, Cr^{+6}, several metals, and CO_2 from two rotary kilns (kiln Nos. 7 and 8) that were fired with liquid hazardous waste. The purpose of the emission test was to demonstrate compliance with regulations promulgated under the authority of RCRA in 40 CFR 266.104(b) through 266.107. The test was conducted in 1992. Process rates were provided on the basis of raw material feed . Emissions from each of the kilns are controlled with a fabric filters.

Particulate matter emissions were measured using Method 5, HCl and chlorine emissions were measured using Method 0050, Method 0012 was used to quantify metals emissions, and Cr^{+6} emissions were measured using Method 0013. Continuous emission monitors were used to measure CO (Method 10), total hydrocarbons (Method 25A), and CO_2 (Method 3A) emissions. Three PM, HCl/chlorine, metals, and Cr^{+6} runs were conducted. Hourly rolling averages of the CO, total hydrocarbons, and CO_2 emissions were recorded, and the average emission rates for each test run

TABLE 4-5. SUMMARY OF SAMPLE ANALYSIS FOR REFERENCE 19 PLANT

Kiln No.	Pollutant	Average concentration, ppm by weight[a]			
		Raw feed	Product	Fabric filter dust	Waste fuel
2	Total chloride	< 0.04	< 0.04	NA	0.67
	Antimony	< 0.115	< 0.0028	< 0.439	< 0.128
	Arsenic	7.27	5.06	274	< 0.026
	Barium	20.9	176	320	< 0.07
	Beryllium	< 0.07	0.88	10.26	< 0.07
	Cadmium	< 0.45	< 0.45	368	< 0.45
	Total chromium	< 0.8	23.6	68.1	1.16
	Lead	7.97	199	21100	< 2.57
	Mercury	< 0.04	< 0.04	0.06	0.09
	Silver	< 0.7	< 0.7	< 0.7	< 0.7
	Thallium	0.735	0.914	1.3	< 0.03

[a]Concentrations below detection limit are indicated with < symbol.

TABLE 4-6. SUMMARY OF TEST DATA FOR REFERENCE 19 PLANT[a]

Kiln No.	Pollutant	No. of runs	Emission factor, kg/Mg			Emission factor, lb/ton		
			Minimum	Maximum	Average	Minimum	Maximum	Average
2	Filterable PM	3	0.18	0.35	0.25	0.36	0.70	0.50
	Hydrogen chloride	3	2.4	2.7	2.6	4.7	5.3	5.1
	Chlorine	3	0.0050	0.019	0.011	0.010	0.037	0.022
	CO2	9	259	338	297	519	675	593
	CO	3	0.41	0.82	0.64	0.83	1.6	1.3
	Total hydrocarbons[b]	4	0.015	0.030	0.024	0.029	0.060	0.047
	Antimony	3	0.0011	0.0050	0.0037	0.0021	0.0099	0.0073
	Arsenic	3	0.037	0.088	0.070	0.074	0.18	0.14
	Barium	3	0.070	0.084	0.079	0.14	0.17	0.16
	Beryllium	3	0.0012	0.0041	0.0025	0.0023	0.0081	0.0051
	Cadmium	3	0.039	0.081	0.066	0.078	0.16	0.13
	Chromium	3	0.016	0.034	0.028	0.032	0.069	0.055
	Copper	3	0.0038	0.0092	0.0072	0.0075	0.018	0.014
	Lead	3	3.2	6.0	4.9	6.3	12	9.7
	Manganese	3	0.040	0.062	0.051	0.081	0.12	0.10
	Nickel	3	0.0081	0.017	0.013	0.016	0.034	0.027
	Phosphorus	3	0.046	0.072	0.063	0.093	0.14	0.13
	Selenium	3	0.00012	0.00027	0.00018	0.00024	0.00053	0.00035
	Silver	3	3.3×10^{-5}	0.00013	7.1×10^{-5}	6.6×10^{-5}	2.5×10^{-5}	0.00014
	Thallium	3	5.4×10^{-5}	0.00015	9.6×10^{-5}	0.00011	0.00031	0.00019
	Zinc	3	0.022	0.039	0.033	0.045	0.079	0.065

[a]All data rated B; emission factors in units of raw material feed rate.
[b]Total hydrocarbons as methane.

were reported. In addition, samples of the raw feed material, finished product, fabric filter dust, and hazardous waste feed material were analyzed for total chlorides and 10 metals. The average concentrations of these chemical constituents are summarized in Table 4-7.

Emission factors were developed for emissions of filterable PM, HCl, chlorine, CO, CO_2, and total hydrocarbons from each of the two kilns. In addition, emission factors were developed for Cr^{+6} and seven metals from one of the two kilns and for nine metals from the other kiln. For some of the metals runs, the concentrations of specific metals (sampling train front half, back half, or both) were below the detection limit. In such cases, the emission factor is based on an assumed concentration of one-half the detection limit for the specific metal. For kiln No. 7, emission factors were not developed for mercury, silver, and thallium emissions because the samples for all runs were below the detection limit for those metals. For the same reason, hexavalent chromium emission factors were not developed from the data for kiln No. 8. The emission data are summarized in Table 4-8.

The emission data for filterable PM, HCl, chlorine, CO_2, and total hydrocarbons are rated B. The test methodologies were sound, and no problems were reported, but the report lacked adequate documentation for a higher rating.

For kiln No. 7, the emission data for arsenic, barium, beryllium, cadmium, hexavalent chromium, and lead are rated B, and the emission data for total chromium are rated C. For kiln No. 8, the emission data for antimony, arsenic, barium, beryllium, cadmium, total chromium, and lead are rated B; the emission data for thallium are rated C; and the emission data for silver are rated D. The test methodologies for the metal emission tests were sound, and no problems were reported. The data were downrated from B to C if, for at least one run, either the front or the back half sample was below the detection limit but the error associated with the undetected samples was no more than approximately 30 percent for any run; the data were downrated from B to D if both the front and back half samples were below the detection limit for one or two runs, or the error associated with the undetected samples was more than approximately 30 percent.

4.2.2 Review of XATEF and SPECIATE Data Base Emission Factors

The XATEF and SPECIATE data bases do not include emission factors for lightweight aggregate production.

4.2.3 Results of Data Analysis

Tables 4-9, 4-10, 4-11, and 4-12 present the emission factors that were developed from References 1 through 16 for lightweight aggregate manufacturing; as indicated previously, the emission factors developed from References 18 to 20 are presented in Tables 4-4, 4-6, and 4-8, respectively. Uncontrolled and controlled emission factors were developed for emissions of filterable PM, condensible PM, filterable PM-10, SO_2, NO_x, CO_2, TVOC's, chlorides, chromium, and lead from lightweight aggregate manufacturing kilns and clinker coolers. The emission factors are expressed in units of mass of pollutant emitted per mass of raw material feed (excluding fuel). The test reports reviewed generally presented process feed rates. For References 3, 5, 6, and 7, it is unclear from the reports if the process data represent feed or production rates. However, the results from the data presented in these four references are consistent with the data presented in the reports that clearly specify process feed rates.

TABLE 4-7. SUMMARY OF SAMPLE ANALYSIS FOR REFERENCE 20 PLANT

Kiln No.	Pollutant	Average concentration, ppm by weight[a]			
		Raw feed	Product	Fabric filter dust	Waste fuel
7	Total chloride	< 0.04	< 0.04	NA	2.53
	Antimony	< 0.39	< 0.45	< 0.33	71.2
	Arsenic	15.5	7.72	118	2.41
	Barium	22.5	22.1	156	144
	Beryllium	< 0.49	0.16	< 0.56	< 0.07
	Cadmium	< 0.45	< 0.45	33.3	17.9
	Total chromium	43.4	64.5	45	216
	Lead	20.1	23.3	269.1	273
	Mercury	< 0.05	0.07	< 0.04	0.21
	Silver	< 0.7	< 0.7	< 0.7	< 0.7
	Thallium	1.23	< 0.46	3.91	< 0.4
8	Total chloride	< 0.04	< 0.04	NA	1.94
	Antimony	< 0.39	< 0.39	< 0.57	6.63
	Arsenic	14.3	9.12	8.38	0.39
	Barium	18.4	40.6	204	152
	Beryllium	< 0.07	0.24	0.46	< 0.17
	Cadmium	< 0.45	< 0.45	39.9	7.22
	Total chromium	35.3	107.3	51.4	68.5
	Lead	23.6	20.2	1347	144
	Mercury	< 0.06	< 0.04	< 0.04	0.76
	Silver	< 0.7	< 0.7	< 0.7	< 0.76
	Thallium	1.24	0.62	4.02	< 0.4

NA = not applicable.
[a]Concentrations below detection limit are indicated with < symbol.

TABLE 4-8. SUMMARY OF TEST DATA FOR REFERENCE 20 PLANT[a]

Kiln No.	Pollutant	No. of runs	Emission factor, kg/Mg			Emission factor, lb/ton			Data Rating
			Minimum	Maximum	Average	Minimum	Maximum	Average	
7	Filterable PM	3	0.041	0.062	0.050	0.083	0.12	0.10	B
	Hydrogen chloride	3	3.1	3.4	3.3	6.1	6.8	6.5	B
	Chlorine	3	0.0026	0.022	0.011	0.0052	0.043	0.022	B
	CO2	9	235	268	255	470	535	509	B
8	Filterable PM	3	0.087	0.22	0.17	0.17	0.44	0.35	B
	Hydrogen chloride	3	1.6	1.8	1.7	3.2	3.6	3.4	B
	Chlorine	3	0.0028	0.0042	0.0036	0.0057	0.0084	0.0072	B
	CO2	9	201	226	214	403	451	427	B
7	Antimony	3	0.00028	0.00045	0.00036	0.00057	0.00091	0.00072	B
	Arsenic	3	3.0×10^{-6}	4.6×10^{-5}	3.1×10^{-5}	6.1×10^{-6}	9.1×10^{-5}	6.19×10^{-5}	B
	Barium	3	2.4×10^{-5}	4.4×10^{-5}	3.5×10^{-5}	4.7×10^{-5}	8.8×10^{-5}	7.05×10^{-5}	B
	Beryllium	3	1.8×10^{-6}	3.3×10^{-6}	2.4×10^{-6}	3.7×10^{-6}	6.5×10^{-6}	4.74×10^{-6}	B
	Cadmium	3	2.4×10^{-6}	3.1×10^{-6}	2.7×10^{-6}	4.9×10^{-6}	6.2×10^{-6}	5.36×10^{-6}	B
	Chromium	3	1.6×10^{-5}	2.5×10^{-5}	2.0×10^{-5}	3.3×10^{-5}	5.0×10^{-5}	3.91×10^{-5}	C
	Hexavalent chromium	3	1.3×10^{-6}	2.9×10^{-6}	2.2×10^{-6}	2.6×10^{-6}	5.8×10^{-6}	4.34×10^{-6}	B
	Lead	3	0.00033	0.0018	0.00090	0.000659	0.0036	0.0018	B
	CO	3	0.051	0.11	0.071	0.10	0.22	0.14	B
	Total hydrocarbons[b]	3	0.0062	0.0093	0.0076	0.012	0.019	0.015	B

TABLE 4-8. (continued)

Kiln No.	Pollutant	No. of runs	Emission factor, kg/Mg			Emission factor, lb/ton			Data Rating
			Minimum	Maximum	Average	Minimum	Maximum	Average	
8	Antimony	3	3.5×10^{-6}	5.7×10^{-5}	2.7×10^{-5}	7.0×10^{-6}	0.000114	5.4×10^{-5}	B
	Arsenic	3	7.1×10^{-5}	0.00017	0.00012	0.000142	0.000331	0.000242	B
	Barium	3	8.0×10^{-5}	9.1×10^{-5}	8.4×10^{-5}	0.00016	0.000182	0.000168	B
	Beryllium	3	2.9×10^{-6}	5.7×10^{-6}	4.6×10^{-6}	5.8×10^{-6}	1.1×10^{-5}	9.2×10^{-6}	B
	Cadmium	3	0.00010	0.00015	0.00012	0.00020	0.000293	0.000239	B
	Chromium	3	4.1×10^{-5}	0.00011	7.5×10^{-5}	8.3×10^{-5}	0.000215	0.000149	B
	Lead	3	0.0019	0.0024	0.0021	0.0038	0.0047	0.0043	B
	Silver	3	2.7×10^{-6}	4.2×10^{-6}	3.5×10^{-6}	5.5×10^{-6}	8.4×10^{-6}	7.0×10^{-6}	D
	Thallium	3	1.6×10^{-6}	2.3×10^{-6}	2.0×10^{-6}	3.1×10^{-6}	4.6×10^{-6}	3.9×10^{-6}	C
	CO	3	0.0074	0.014	0.011	0.015	0.028	0.022	B
	Total hydrocarbons[b]	3	0.0058	0.011	0.0083	0.012	0.023	0.017	B

[a]Emission factors in units of raw material feed rate.
[b]Total hydrocarbons as methane.

Table 4-9 presents the emission factors developed for lightweight aggregate manufacturing kilns. The table includes the number of test runs, the data rating, the emission factor range, and the average emission factor for each test. Although several of the references used to develop these emission factors did not specify the type of kiln tested, rotary kilns generally are used in the industry, and it is assumed that the emission factors in Table 4-9 represent rotary kiln emissions. The emission factors generally are consistent for the same combination of pollutant and control device. The only major inconsistency in kiln emission factor magnitude is the emission factors for uncontrolled filterable PM emissions, which range from 6.5 to 170 kg/Mg (13 to 340 lb/ton) and average 65 kg/Mg (130 lb/ton).

For the emission test reports reviewed, wet scrubbers were the most commonly used device to control kiln emissions. The majority of the reports contains little information on the types of scrubbers used. All of the reports that include information on the type of scrubber indicate that the scrubbers were of medium energy design.

Table 4-10 presents particle size distribution and size-specific emission factors for rotary kilns developed from two emission tests and the average of the tests. These data were used to develop the filterable PM-10 emission factors presented in Table 4-9. Table 4-11 presents the emission factors developed for emissions from clinker coolers. The filterable PM-10 emission factors presented in Table 4-11 were developed from particle size distribution data. The table includes the number of test runs, data ratings, emission factor range, and average emission factor for each test. Particle size distribution and size-specific emission factors for clinker cooler emissions are summarized in Table 4-12.

Table 4-13 presents a summary of the average emission factors developed for AP-42 Section 8.25, Lightweight Aggregate Manufacturing. The emission factors in Table 4-13 generally are based on the A- and B-rated tests described in Section 4.2 of this report. The emission factors developed for chloride, chlorine, HCl, metals, and total hydrocarbon emissions from kilns fired with hazardous waste (References 5, 18, 19, and 20) have not been incorporated in the AP-42 section; the magnitude of emissions of these pollutants is largely a function of the waste fuel composition, which can vary considerably. The emission factors for controlled filterable PM emissions developed from Reference 5, and for filterable PM, CO_2, and SO_2 developed from Reference 9, which are based on D-rated data, have not been averaged into the emission factors in Table 4-7. In addition, the CO_2 emission factors from References 15 and 16, which are based on C-rated data, also are not included in the average emission factors presented in Table 4-7.

The majority of emission factors listed in Table 4-13 are based on one, two, or three emission tests. Because of the relatively large number of domestic lightweight aggregate manufacturing plants (51), it is likely that the emission factors based on three tests or less are not representative of the industry as a whole. For that reason, these emission factors are rated D. The emission factors for uncontrolled and controlled SO_2 emissions, uncontrolled filterable PM, fabric filter-controlled filterable PM, and uncontrolled CO_2 emissions from lightweight aggregate kilns are based on 4 to 11 emission tests. Although these emission factors are based on A- and B-rated data, it is unclear if the tests represent a random sample of the industry, and the emission factors are rated C.

TABLE 4-9. SUMMARY OF TEST DATA FOR LIGHTWEIGHT AGGREGATE KILNS

Type of control	Pollutant	No. of test runs	Data rating	Emission factor		Ref. No.
				Range kg/Mg (lb/ton)	Average kg/Mg (lb/ton)	
None	CO_2	6	A	260-290 (520-570)	270 (540)	1
None	Condensible inorganic PM	2	A	0.26-0.35 (0.52-0.70)	0.30 (0.61)	1
None	Condensible organic PM	2	A	0.0087-0.11 (0.014-0.017)	0.0080 (0.016)	1
None	Filterable PM	2	A	166-168 (332-335)	170 (330)	1
None	SO_2	3	A	3.7-4.4 (7.3-8.7)	4.1 (8.2)	1
Wet scrubber	Condensible inorganic PM	3	A	0.095-0.095 (0.19-0.19)	0.095 (0.19)	1
Wet scrubber	Condensible organic PM	3	A	0.0033-0.0050 (0.0066-0.010)	0.0042 (0.0083)	1
Wet scrubber	Filterable PM	3	A	0.25-0.28 (0.50-0.55)	0.27 (0.53)	1
Wet scrubber	TVOC's	4	A	0.23-0.70 (0.46-1.4)	0.39 (0.78)	1
Wet scrubber	NO_x	3	A	0.95-0.97 (1.9-1.9)	0.96 (1.9)	1
Wet scrubber	Filterable PM-10	2	A	0.043-0.047 (0.085-0.094)	0.045 (0.090)	1
Wet scrubber	SO_2	3	A	0.70-1.2 (1.4-2.4)	1.0 (2.0)	1
None	SO_2	3	A	2.0-2.1 (4.0-4.2)	2.1 (4.1)	2
Wet scrubber	NO_x	3	A	1.0-1.1 (2.0-2.2)	1.1 (2.1)	2
Wet scrubber	SO_2	3	A	1.3-1.3 (2.5-2.6)	1.3 (2.6)	2
None	CO_2	6	A	180-270 (350-530)	220 (440)	2
None	SO_2	3	B	1.6-1.9 (3.2-3.8)	1.7 (3.4)	3
None	CO_2	3	B	220-220 (430-440)	220 (430)	3

TABLE 4-9. (continued)

Type of control	Pollutant	No. of test runs	Data rating	Emission factor		Ref. No.
				Range kg/Mg (lb/ton)	Average kg/Mg (lb/ton)	
Wet scrubber	Condensible inorganic PM	3	B	0.087-0.098 (0.17-0.20)	0.092 (0.18)	3
Wet scrubber	Condensible organic PM	3	B	0.004-0.006 (0.007-0.012)	0.005 (0.010)	3
Wet scrubber	Filterable PM	3	B	0.27-0.32 (0.53-0.63)	0.29 (0.57)	3
Wet scrubber	NO_x	3	B	0.84-0.91 (1.7-1.8)	0.86 (1.7)	3
Wet scrubber	Filterable PM-10	4	B	0.22-0.26 (0.44-0.53)	0.24 (0.48)	3
Wet scrubber	SO_2	3	B	1.5-1.6 (3.0-3.1)	1.5 (3.1)	3
None	Chloride	2	B	0.60-0.65 (1.20-1.30)	0.63 (1.3)	5
None	Chromium	2	B	0.0025-0.0032 (0.0050-0.0064)	0.0029 (0.0057)	5
None	Filterable PM	2	B	6.3-6.7 (12.5-13.3)	6.5 (13)	5
None	Lead	2	B	0.0006-0.0009 (0.0012-0.0017)	0.00075 (0.0015)	5
Unspecified controls	Chloride	3	D	0.12-0.21 (0.25-0.42)	0.18 (0.36)	5
Unspecified controls	Chromium	3	D	0.0003-0.0013 (0.0006-0.0026)	6.5×10^{-5} (0.00013)	5
Unspecified controls	Filterable PM	3	D	0.11-0.25 (0.21-0.49)	0.16 (0.32)	5
Unspecified controls	Lead	3	D	5×10^{-5}-0.0002 (0.0001-0.0004)	0.00015 (0.00030)	5
None	SO_2	3	B	3.3-3.5 (6.5-7.0)	3.4 (6.8)	6
Wet scrubber	SO_2	3	B	2.9-3.2 (5.8-6.4)	3 (6.0)	7
Mech. collector+ wet scrubber	Filterable PM	3	B	0.33-0.69 (0.65-1.4)	0.50 (1.0)	8
Wet scrubber	Filterable PM	3	D	0.63-1.1 (1.3-2.2)	0.70 (1.6)	9

TABLE 4-9. (continued)

Type of control	Pollutant	No. of test runs	Data rating	Emission factor		Ref. No.
				Range kg/Mg (lb/ton)	Average kg/Mg (lb/ton)	
Wet scrubber	CO_2	3	D	170-200 (340-390)	190 (370)	9
Wet scrubber	SO_2	3	D	0.050-0.21 (0.10-0.42)	0.12 (0.23)	9
Mech. collector+ wet scrubber	Filterable PM	3	B	0.60-1.5 (1.2-2.9)	0.90 (1.8)	11
Multiclone + wet scrubber	Filterable PM	3	B	0.26-0.30 (0.52-0.59)	0.28 (0.56)	12
Multiclone + wet scrubber	CO_2	3	B	210-220 (420-430)	210 (420)	12
Wet scrubber	Filterable PM	3	B	0.37-0.43 (0.74-0.86)	0.41 (0.81)	13
Wet scrubber	CO_2	3	B	200-200 (390-400)	200 (390)	13
None	Filterable PM	3	B	15-17 (29-34)	16 (32)	14
None	Condensible inorganic PM	3	B	0.25-0.90 (0.49-1.8)	0.50 (1.0)	14
None	CO_2	6	B	40-120 (80-240)	90 (170)	14
Fabric filter	Filterable PM	3	B	0.12-0.45 (0.24-0.89)	0.26 (0.52)	14
Fabric filter	Condensible inorganic PM	3	B	0.033-0.10 (0.065-0.20)	0.070 (0.14)	14
ESP	Filterable PM	3	B	0.34-0.46 (0.67-0.91)	0.40 (0.79)	15
ESP	Condensible inorganic PM	3	B	0.0080-0.020 (0.016-0.040)	0.0140 (0.028)	15
None	CO_2	3	C	150-160 (300-310)	160 (310)	15
ESP	Filterable PM	3	B	0.21-0.33 (0.42-0.65)	0.28 (0.55)	16
ESP	Condensible inorganic PM	3	B	0.012-0.026 (0.023-0.052)	0.017 (0.033)	16

TABLE 4-9. (continued)

Type of control	Pollutant	No. of test runs	Data rating	Emission factor		Ref. No.
				Range kg/Mg (lb/ton)	Average kg/Mg (lb/ton)	
None	CO_2	3	C	160-180 (310-360)	170 (340)	16

TABLE 4-10. SUMMARY OF PARTICLE SIZE DATA FOR EMISSIONS FROM ROTARY KILNS

Reference 1

Diameter, microns	Controlled (scrubber)		
	Cumulative % less than diameter	Emission factor	
		kg/Mg	lb/ton
2.5	13	0.034	0.069
6.0	15	0.040	0.080
10.0	17	0.045	0.090
15.0	19	0.050	0.101
20.0	20	0.053	0.106

Reference 3

Diameter, microns	Controlled (scrubber)		
	Cumulative % less than diameter	Emission factor	
		kg/Mg	lb/ton
2.5	56	0.16	0.32
6.0	76	0.22	0.44
10.0	83	0.24	0.48
15.0	90	0.26	0.52
20.0	93	0.27	0.53

Average

Diameter, microns	Controlled (scrubber)		
	Cumulative % less than diameter	Emission factor	
		kg/Mg	lb/ton
2.5	35	0.10	0.20
6.0	46	0.13	0.26
10.0	50	0.14	0.28
15.0	55	0.15	0.31
20.0	57	0.16	0.32

TABLE 4-11. SUMMARY OF TEST DATA FOR LIGHTWEIGHT AGGREGATE CLINKER COOLERS

Type of control	Pollutant	No. of test runs	Data rating	Emission factor		Ref. No.
				Range kg/Mg (lb/ton)	Average kg/Mg (lb/ton)	
Settling chamber	Condensible inorganic PM	3	A	0.0085-0.013 (0.017-0.025)	0.011 (0.021)	1
Settling chamber	Condensible organic PM	3	A	$1.2x10^{-4}$ - $4.9x10^{-4}$ ($2.1x10^{-4}$ - $9.7x10^{-4}$	2.8×10^{-4} (5.5×10^{-4})	1
Settling chamber	Filterable PM	3	A	0.050-0.080 (0.10-0.16)	0.066 (0.13)	1
Settling chamber	Filterable PM-10	4	A	0.013-0.021 (0.026-0.042)	0.017 (0.034)	1
Multiclone	CO_2	3	A	14-36 (28-71)	22 (43)	2
Multiclone	Condensible inorganic PM	4	A	$1.0x10^{-5}$ - 0.0033 ($2.0x10^{-5}$ - 0.0065)	0.0013 (0.0025)	2
Multiclone	Condensible organic PM	4	A	0.00090-0.0019 (0.0018-0.0038)	0.0014 (0.0027)	2
Multiclone	Filterable PM	4	A	0.10-0.21 (0.20-0.41)	0.15 (0.30)	2
Multiclone	Filterable PM-10	3	A	0.040-0.080 (0.080-0.16)	0.060 (0.12)	2
Settling chamber	Condensible inorganic PM	3	A	0.0039-0.011 (0.0079-0.022)	0.0065 (0.013)	4
Settling chamber	Condensible organic PM	3	A	0.0029-0.0048 (0.0059-0.0097)	0.0039 (0.0078)	4
Settling chamber	Filterable PM	3	A	0.19-0.24 (0.37-0.49)	0.22 (0.43)	4
Settling chamber	Filterable PM-10	3	A	0.083-0.11 (0.17-0.21)	0.095 (0.19)	4

TABLE 4-12. SUMMARY OF PARTICLE SIZE DATA FOR EMISSIONS FROM CLINKER COOLERS

Reference 1

Diameter (microns)	Controlled (settling chamber)		
	Cumulative % less than diameter	Emission factor	
		kg/Mg	lb/ton
2.5	8	0.0052	0.010
6.0	18	0.012	0.023
10.0	26	0.017	0.034
15.0	34	0.022	0.044
20.0	40	0.026	0.052

Reference 4

Diameter, microns	Controlled (settling chamber)		
	Cumulative % less than diameter	Emission factor	
		kg/Mg	lb/ton
2.5	10	0.022	0.043
6.0	24	0.052	0.10
10.0	44	0.095	0.19
15.0	64	0.14	0.28
20.0	75	0.16	0.32

Average

Diameter, microns	Controlled (settling chamber)		
	Cumulative % less than diameter	Emission factor	
		kg/Mg	lb/ton
2.5	9	0.013	0.027
6.0	21	0.032	0.063
10.0	35	0.056	0.11
15.0	49	0.080	0.16
20.0	58	0.094	0.19

Reference 2

Diameter (microns)	Controlled (dry multicyclone)		
	Cumulative % less than diameter	Emission factor	
		kg/Mg	lb/ton
2.5	19	0.029	0.057
6.0	31	0.047	0.093
10.0	40	0.060	0.12
15.0	48	0.072	0.14
20.0	53	0.080	0.16

TABLE 4-13. SUMMARY OF EMISSION FACTORS DEVELOPED FOR LIGHTWEIGHT AGGREGATE MANUFACTURING

Process	Type of control	Pollutant	No. of tests	Average emission factor, kg/Mg (lb/ton)	Emission factor rating	Ref. Nos.
Rotary kiln	None	CO	5	0.29 (0.59)	C	18,19,20
Rotary kiln	None	SO_2	4	2.8 (5.6)	C	1,2,3,6
Rotary kiln	None	CO_2	11	240 (480)	C	1,2,3,12, 13,14,18, 19,20
Rotary kiln	None	Filterable PM	3	65 (130)	D	1,5,14
Rotary kiln	None	Condensible organic PM	1	0.0080 (0.016)	D	1
Rotary kiln	None	Condensible inorganic PM	2	0.41 (0.81)	D	1.14
Rotary kiln	Scrubber	Filterable PM	6	0.39 (0.77)	C	1,3,8,11,1 2,13
Rotary kiln	Scrubber	Condensible organic PM	2	0.0046 (0.0092)	D	1,3
Rotary kiln	Scrubber	Condensible inorganic PM	2	0.10 (0.19)	D	1,3
Rotary kiln	Scrubber	Filterable PM-10	2	0.15 (0.29)	D	1,3
Rotary kiln	Scrubber	Hydrocarbons	1	0.39 (0.78)	D	1
Rotary kiln	Scrubber	NO_x	3	1.0 (1.9)	D	1,2,3
Rotary kiln	Scrubber	SO_2	4	1.7 (3.4)	C	1,2,3,7
Rotary kiln	Fabric filter	Filterable PM	6	0.13 (0.26)	C	5,14,18-20
Rotary kiln	Fabric filter	Condensible inorganic PM	1	0.070 (0.14)	D	14
Rotary kiln	ESP	Filterable PM	2	0.34 (0.67)	D	15,16
Rotary kiln	ESP	Condensible inorganic PM	2	0.015 (0.031)	D	15,16
Clinker cooler	Settling chamber	Filterable PM	2	0.14 (0.28)	D	1,4

TABLE 4-13. (continued)

Process	Type of control	Pollutant	No. of tests	Average emission factor, kg/Mg (lb/ton)	Emission factor rating	Ref. Nos.
Clinker cooler	Settling chamber	Condensible organic PM	2	0.00034 (0.00067)	D	1,4
Clinker cooler	Settling chamber	Condensible inorganic PM	2	0.0085 (0.017)	D	1,4
Clinker cooler	Settling chamber	Filterable PM-10	2	0.055 (0.11)	D	1,4
Clinker cooler	Multiclone	Filterable PM	1	0.15 (0.30)	D	2
Clinker cooler	Multiclone	Condensible organic PM	1	0.0014 (0.0027)	D	2
Clinker cooler	Multiclone	Condensible inorganic PM	1	0.0013 (0.0025)	D	2
Clinker cooler	Multiclone	Filterable PM-10	1	0.060 (0.12)	D	2
Clinker cooler	Multiclone	CO_2	1	22 (43)	D	2

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18. Emission Test Results for No. 2 and No. 4 Aggregate Kilns, Solite Corporation, Leaksville Plant, Cascade, Virginia, IEA, Research Triangle Park, NC, August 8, 1992.

19. Emission Test Results for No. 2 Aggregate Kiln, Solite Corporation, Hubers Plant, Brooks, Kentucky, IEA, Research Triangle Park, NC, August 12, 1992.

20. Emission Test Results for No. 7 and No. 8 Aggregate Kilns, Solite Corporation, A. F. Old Plant, Arvonia, Virginia, IEA, Research Triangle Park, NC, August 8, 1992.