Emission Factor Documentation for AP-42
Section 11.15

Lime Manufacturing

Final Report

For U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Inventory Branch

EPA Contract 68-D2-0159
Work Assignment No. I-01

MRI Project No. 4601-01

April 28, 1994

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Final Report

For U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Inventory Branch
Research Triangle Park, NC 27711

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Emission Factor and Methodology

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PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Office of Air Quality Planning and Standards (OAQPS), U. S. Environmental Protection Agency (EPA), under Contract No. 68-D2-0159, Work Assignment No. I-01. Mr. Ron Myers was the requester of the work. The report was prepared by Richard Marinshaw, Dennis Wallace, Brian Shrager, and Ed Sanderford.

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April 28, 1994

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1. INTRODUCTION

The document Compilation of Air Pollutant Emission 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 revision of AP-42 Section 11.15, Lime Manufacturing.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the Lime Manufacturing 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 lime manufacturing. Section 3 is a review of emission data collection and laboratory 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 a review of specific data sets and the results of data analysis. Section 5 presents AP-42 Section 11.15, Lime Manufacturing.

2. INDUSTRY DESCRIPTION[1-5]

Lime is the high-temperature product of the calcination of limestone. Although limestone deposits are found in every State, only a small portion is pure enough for industrial lime manufacturing. To be classified as limestone, the rock must contain at least 50 percent calcium carbonate ($CaCO_3$). When the rock contains 30 to 45 percent magnesium carbonate, it is referred to as dolomite, or dolomitic limestone. Lime can also be produced from aragonite, chalk, coral, marble, and sea shells.

The Standard Industry Classification (SIC) code for lime manufacturing is 3274. The first six digits of lime manufacturing Source Classification Codes (SCC) are 3-05-016.

2.1 CHARACTERIZATION OF THE INDUSTRY[1,2,5]

During 1989, approximately 15.6 million megagrams (Mg) (17.1 million tons) of lime were produced at 116 U.S. plants. Table 2-1

TABLE 2-1. 1989 DOMESTIC LIME PRODUCTION BY STATE[5]

State	No. of plants	Production		Value, thousands, $
		Mg	tons	
Alabama	5	1,344	1,481	70,361
Arizona	3	W	W	W
Arkansas, Louisiana, Oklahoma	3	259	286	15,548
California	11	358	395	24,503
Colorado, Nevada, Wyoming	9	324	357	24,136
Hawaii, Oregon, Washington	4	357	393	26,348
Idaho	3	W	W	W
Illinois, Indiana, Missouri	8	3,315	3,654	168,979
Iowa, Nebraska, South Dakota	4	W	W	W
Kentucky, Tennessee, West Virginia	5	1,473	1,624	89,859
Massachusetts	2	W	W	W
Michigan	8	563	621	32,479
Minnesota and Montana	7	W	W	W
North Dakota	3	97	108	5,439
Ohio	9	1,713	1,888	94,157
Pennsylvania	10	1,506	1,660	92,139
Puerto Rico	1	24	26	3,800
Texas	8	1,183	1,304	60,829
Utah	4	338	373	17,974
Virginia	5	745	821	38,353
Wisconsin	4	396	437	181,129
Other	a	1,588	1,750	72,880
TOTAL	116	15,584	17,178	855,913

[a]Included with data for individual States. W = withheld to avoid disclosing company proprietary data; included in other.

summarizes domestic lime production by State in 1989.

There are two kinds of lime: high-calcium lime (CaO) and dolomitic lime (CaO·MgO). More than 90 percent of limestone mines are from open-pit operations; the remainder are underground. The major uses of lime are metallurgical (aluminum, steel, copper, silver, and gold industries), environmental (flue gas desulfurization, water softening, pH control, sewage-sludge destabilization, and hazardous waste treatment), and construction (soil stabilization, asphalt additive, and masonry lime). In 1989, about 14 percent of all lime produced was converted to hydrated (slaked) lime, and 3.6 percent was converted to dead-burned dolomite. Dead-burned dolomitic lime, or refractory lime, is a sintered form of dolomitic lime that is calcined at high temperatures with the addition of iron oxide. Dead-burned dolomitic lime is used primarily as a refractory for lining steel furnaces.

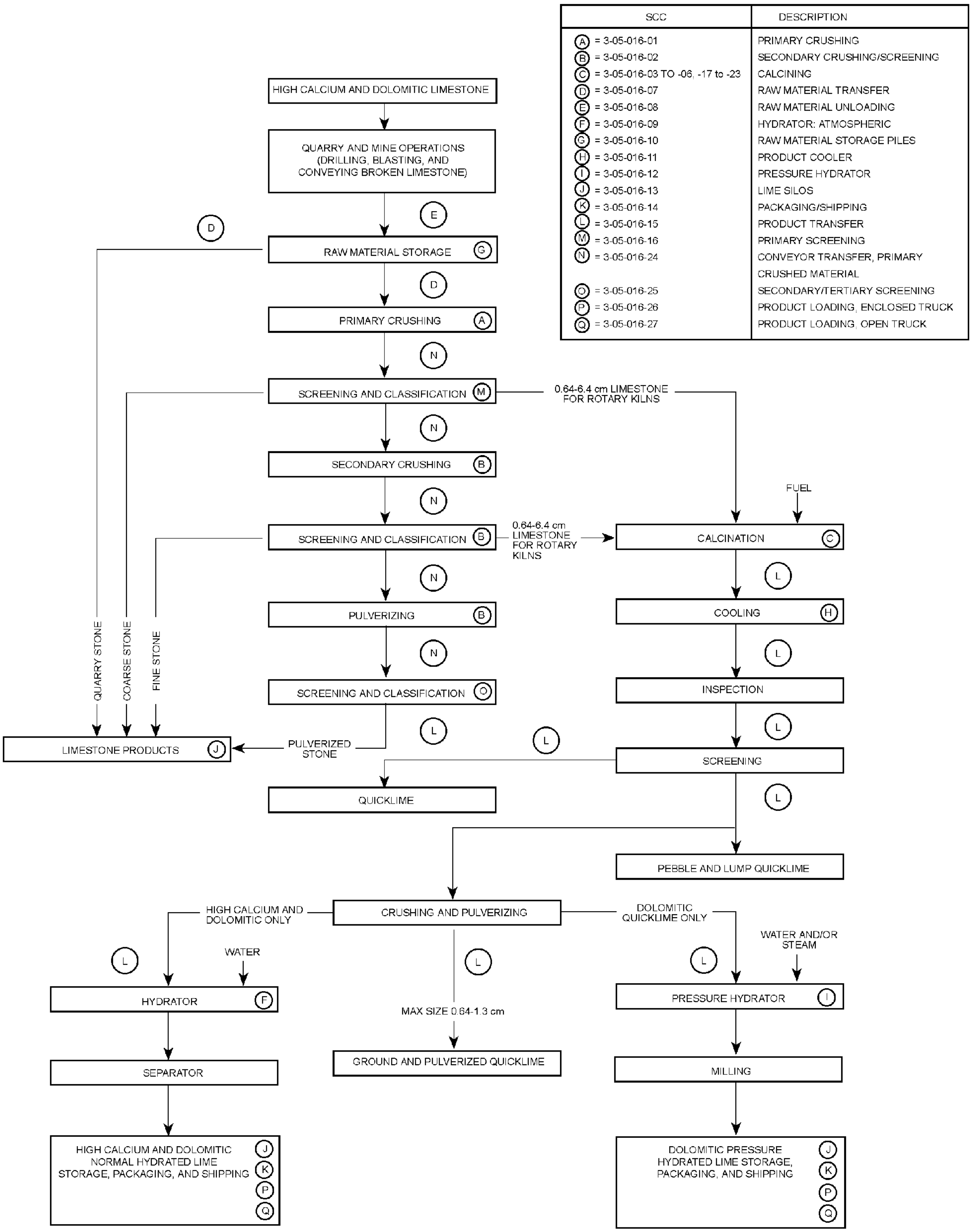
2.2 PROCESS DESCRIPTION[1-4,6]

Lime is manufactured in various kinds of kilns by one of the following reactions:

$CaCO_3$ + heat $\rightarrow$ CO_2 + CaO (high-calcium lime)

$CaCO_3 \cdot MgCO_3$ + heat $\rightarrow$ 2 CO_2 + CaO·MgO (dolomitic lime)

The basic processes in the production of lime are (1) quarrying raw limestone; (2) preparing the limestone for the kilns by crushing and sizing; (3) calcining the limestone; (4) processing the lime further by hydration; and (5) miscellaneous transfer, storage, and handling operations. A generalized material flow diagram for a lime manufacturing plant is given in Figure 2-1



SCC	DESCRIPTION
A = 3-05-016-01	PRIMARY CRUSHING
B = 3-05-016-02	SECONDARY CRUSHING/SCREENING
C = 3-05-016-03 TO -06, -17 to -23	CALCINING
D = 3-05-016-07	RAW MATERIAL TRANSFER
E = 3-05-016-08	RAW MATERIAL UNLOADING
F = 3-05-016-09	HYDRATOR: ATMOSPHERIC
G = 3-05-016-10	RAW MATERIAL STORAGE PILES
H = 3-05-016-11	PRODUCT COOLER
I = 3-05-016-12	PRESSURE HYDRATOR
J = 3-05-016-13	LIME SILOS
K = 3-05-016-14	PACKAGING/SHIPPING
L = 3-05-016-15	PRODUCT TRANSFER
M = 3-05-016-16	PRIMARY SCREENING
N = 3-05-016-24	CONVEYOR TRANSFER, PRIMARY CRUSHED MATERIAL
O = 3-05-016-25	SECONDARY/TERTIARY SCREENING
P = 3-05-016-26	PRODUCT LOADING, ENCLOSED TRUCK
Q = 3-05-016-27	PRODUCT LOADING, OPEN TRUCK

Figure 2-1. Process flow diagram for lime manufacturing.[4]

. Note that some operations shown may not be performed in all plants.

The heart of a lime plant is the kiln. The prevalent type of kiln is the rotary kiln, accounting for about 90 percent of all lime production in the United States. This kiln is a long, cylindrical, slightly inclined, refractory-lined furnace through which the limestone and hot combustion gases pass countercurrently. Coal, oil, and natural gas may all be fired in rotary kilns. Product coolers and limestone preheaters of various types are commonly used to recover heat from the hot lime product and hot exhaust gases, respectively.

The next most common type of kiln in the United States is the vertical, or shaft, kiln. This kiln can be described as an upright heavy steel cylinder lined with refractory material. The limestone is charged at the top and is calcined as it descends slowly to discharge at the bottom of the kiln. A primary advantage of vertical kilns over rotary kilns is higher average fuel efficiency. The primary disadvantages of vertical kilns are their relatively low production rates and the fact that coal cannot be used without degrading the quality of the lime produced. There have been few recent vertical kiln installations in the United States because of high product quality requirements.

Other, much less common, kiln types include rotary hearth and fluidized bed kilns. Both kiln types can achieve high production rates, and neither can operate with coal. The "calcimatic" kiln, or rotary hearth kiln, is a circular kiln with a slowly revolving doughnut-shaped hearth. In fluidized bed kilns, finely divided limestone is brought into contact with hot combustion air in a turbulent zone, usually above a perforated grate. Because of the amount of lime carryover into the exhaust gases, dust collection equipment must be installed on fluidized bed kilns for process economy.

Another alternative process that is beginning to emerge in the United States is the parallel flow regenerative (PR) lime kiln. This process combines two advantages. First, optimum heating conditions for lime calcining are achieved by concurrent flow of the charge material and combustion gases. Second, the multiple-chamber regenerative process uses the charge material as the heat transfer medium to preheat the combustion air. The basic PR system has two shafts, but three-shaft systems are used with small size grains to address the increased flow resistance associated with smaller feed sizes.

In the two-shaft system, the shafts alternate functions, with one shaft serving as the heating shaft and the other as the flue gas shaft. Figure 2-2

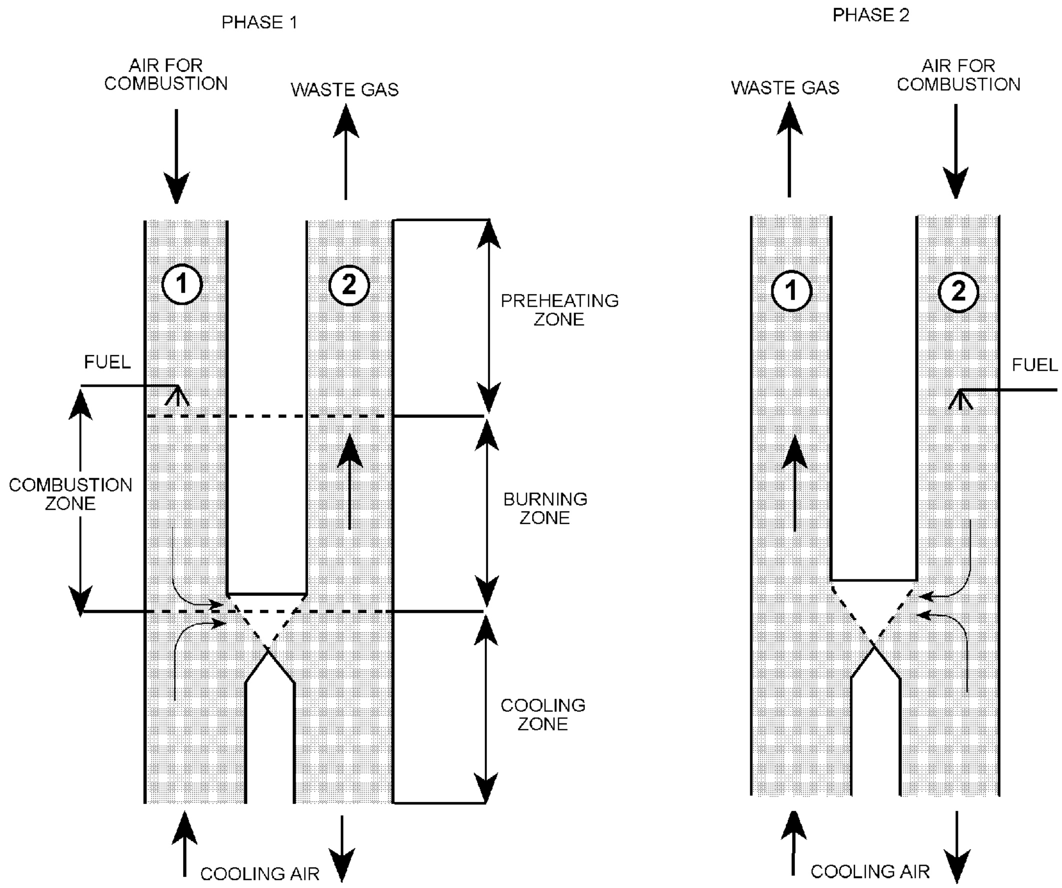


Figure 2-2. Operation of parallel flow regenerative lime kiln.[6]

illustrates the operation of the two-shaft PR kiln. Each shaft includes a heating zone, a combustion/burning zone, and a cooling zone. Limestone is charged alternatively to the two shafts and flows downward by gravity flow. The two shafts are connected in the middle to allow gas flow between them. In the heating shaft, combustion air flows downward through the heated charge material. After being preheated by the charge material, the combustion air combines with the fuel (natural gas or oil), and the air/fuel mixture is fired downward into the combustion zone. The hot combustion gases pass from the combustion zone in the heating shaft to the combustion zone in the flue gas shaft. The heated exhaust gases flow upward through the flue gas shaft combustion zone and into the preheating zone where they heat the charge material. The function of the two shafts reverses on a 12-minute cycle. The bottom of both shafts is a cooling zone. Cooling air flows upward through the shaft countercurrently to the flow of the calcined product. This air mixes with the combustion gases in the crossover area providing additional combustion air. The product flows by gravity from the bottom of both shafts.

About 15 percent of all lime produced is converted to hydrated (slaked) lime. There are two kinds of hydrators, atmospheric and pressure. Atmospheric hydrators, the more prevalent type, are used in continuous mode to produce high-calcium and dolomitic hydrates. Pressure hydrators, on the other hand, produce only a completely hydrated dolomitic lime and operate only in batch mode. Generally, water sprays or wet scrubbers perform the hydrating process and prevent product loss. Following hydration, the product may be milled and then conveyed to air separators for further drying and removal of coarse fractions.

2.3 EMISSIONS[1-4,7]

Potential air pollutant emission points in lime manufacturing plants are indicated by SCC in Figure 2-1. Except for gaseous pollutants emitted from kilns, particulate matter (PM) is the dominant pollutant. Emissions of filterable PM from rotary lime kilns constructed or modified after May 3, 1977 are regulated to 0.30 kilograms per megagram (kg/Mg) (0.60 pounds per ton [lb/ton]) of stone feed under 40 CFR Part 60, subpart HH.

The largest ducted source of PM is the kiln. Of the various kiln types, fluidized beds have the highest levels of uncontrolled PM emissions because of the very small feed rate combined with high air flow through these kilns. Fluidized bed kilns are well controlled for maximum product recovery. The rotary kiln is second worst in uncontrolled PM emissions because of the small feed rate, the relatively high air velocities, and the dust entrainment caused by the rotating chamber. The calcimatic (rotary hearth) kiln ranks third in dust production, primarily because of the larger feed size and the fact that, during calcination, the limestone remains stationary relative to the hearth. The vertical kiln has the lowest uncontrolled dust emissions due to the large lump feed, the relatively low air velocities, and the slow movement of material through the kiln. In coal-fired kilns, the properties of the limestone feed and the ash content of the coal can significantly affect PM emission rates.

Carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrous oxides (NO_x) are all produced in kilns. Sulfur dioxide emissions are influenced by the sulfur content of the fuel, the sulfur content of the stone feed, the mineralogical forms (pyritic or gypsum) of the stone feed, the quality of lime being manufactured, and the type of kiln. The dominant source of sulfur emissions is the kiln fuel, and the vast majority of the fuel sulfur is not emitted because of reactions with calcium oxides in the kiln. Sulfur dioxide emissions may be further reduced if the pollution equipment uses a wet process or if it brings CaO and SO_2 into intimate contact.

Product coolers are emission sources only when some of their exhaust gases are not recycled through the kiln for use as combustion air. The trend is toward recycling cooler exhaust as combustion air to maximize fuel efficiencies. This reduces emissions from product coolers.

Hydrator emissions are low, because water sprays or wet scrubbers are usually installed to prevent product loss in the exhaust gases. Emissions from pressure hydrators may be higher than from the more common atmospheric hydrators because the exhaust gases are released intermittently, making control more difficult.

Other particulate sources in lime plants include primary and secondary crushers, mills, screens, mechanical and pneumatic transfer operations, storage piles, and roads. If quarrying is a part of the lime plant operation, particulate may also result from drilling and blasting. Emission factors for some of these operations are presented in Sections 11.19 and 13.2 of AP-42.

2.4 CONTROL TECHNOLOGY[4]

Some sort of particulate control is generally applied to most kilns. Rudimentary fallout chambers and cyclone separators are commonly used to control larger particles. Fabric and gravel bed filters, wet (commonly, venturi) scrubbers, and electrostatic precipitators (ESP's) are used for secondary control.

For particulate control, cyclones, fabric filters, and wet scrubbers are also used on coolers and ducted emission sources such as crushers and loaders.

REFERENCES FOR SECTION 2

1. *Screening Study For Emissions Characterization From Lime Manufacture*, EPA Contract No. 68-02-0299. Vulcan-Cincinnati, Inc., Cincinnati, OH. August 1974.

2. *Standards Support And Environmental Impact Statement, Volume I: Proposed Standards Of Performance For Lime Manufacturing Plants*, EPA-450/2-77-007a, U. S. Environmental Protection Agency, Research Triangle Park, NC. April 1977.

3. National Lime Association, Lime Manufacturing, *Air Pollution Engineering Manual*, Buonicore, Anthony J. and Wayne T. Davis (eds.), Air and Waste Management Association, Van Nostrand Reinhold, New York. 1992.

4. J. S. Kinsey, *Lime And Cement Industry--Source Category Report, Volume I: Lime Industry*, EPA-600/7-86-031, U. S. Environmental Protection Agency, Cincinnati, OH, September 1986.

5. M. Miller, Lime, *Minerals Yearbook, Volume I, Metals and Minerals*, Bureau of Mines, U.S. Department of the Interior, Washington, D.C., 1991.

6. Written communication from J. Bowers, Chemical Lime Group, Fort Worth, TX, to R. Marinshaw, Midwest Research Institute, Cary, NC, October 28, 1992.

7. Written communication from A. Seeger, Morgan, Lewis & Bockius, to R. Myers, U. S. Environmental Protection Agency, RTP, NC, November 3, 1993.

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 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) 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, Census of Minerals, Census of Manufacturers,* and other sources. The Aerometric Information Retrieval System (AIRS) data base also was searched for data on the number of plants, plant locations, 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 lime 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, Census of Manufacturers, Census of Minerals*, 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 lime manufacturing industry. In addition, the National Lime Association was contacted for assistance in obtaining information about the industry and emissions.

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 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 and analysis procedures. The sampling and analysis 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. Data 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 statistical analysis of the test data was rated using 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, EPA-454/B-93-050,* Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1993.

4.0 AP-42 SECTION DEVELOPMENT

4.1 REVISION OF SECTION NARRATIVE

The section narrative was expanded to include a description of the parallel flow regenerative lime kiln, also known as the Maertz kiln, which had not been addressed in the previous version of AP-42. Other than minor editorial changes, no other changes were made to the section narrative.

4.2 POLLUTANT EMISSION FACTOR DEVELOPMENT

A total of 50 documents were reviewed in the process of developing emission factors for this revision to AP-42. The majority of the data for this revision were obtained from the background file for the AP-42 section. In addition, five new test reports (References 23 through 26 and Reference 50) that were not in the background file were reviewed. Table 4-1

TABLE 4-1. SUMMARY OF EMISSION TEST REPORTS USED TO DEVELOP EMISSION FACTORS

Company name	Plant location	Sources tested	Pollutants	Year	Ref.
J. M. Brenner	Lancaster, PA	Primary crusher, screens, hammermill, final sizing screens	PM	1974	2
Marblehead Lime	Bellefonte, PA	Rotary kiln	PM	1975	3
J. E. Baker	Millersville, OH	Rotary kiln	PM, CO_2	1975	5
Virginia Lime	Ripplemead, VA	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1975	6
Pfizer, Inc.	Gibsonburg, OH	Rotary kiln Materials transfer Product loading	PM	1980	7
Standard Lime	Woodville, OH	Rotary kiln	PM, NO_x, CO_2	1975	8
Dow Chemical	Freeport, TX	Rotary kiln	PM, NO_x, CO_2	1974	9
J. E. Baker	Millersville, OH	Rotary kiln	PM, SO_2, SO3, CO_2	1974	10
J. E. Baker	Millersville, OH	Rotary kiln	PM, SO_2, CO_2	1975	11
Paul Lime Plant	Millersville, OH	Rotary kiln	PM	1975	12
U.S. Lime	Nelson, AZ	Rotary kiln	PM, SO_2, CO_2	1975	13
Allied Products	Montevallo, AL	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1975	14
Martin-Marietta	Calera, AL	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1975	15
		Atmospheric hydrator	PM		
Plant No. 1		Rotary kiln	PM, CO_2	1977	16
Plant No. 2		Rotary kiln	PM, CO_2	1977	17
Plant No. 3		Rotary kiln	PM, CO_2	1977	18
U.S. Lime	City of Industry, CA	Atmospheric hydrator	PM, CO_2	1974	19
National Lime and Stone	Carey, OH	Calcimatic kiln	PM, NO_x, CO_2	1974	20
		Cooler	PM, CO_2		
Martin-Marietta	Woodville, OH	Rotary kiln	SO_2, CO_2	1976	21
		Rotary kiln with preheater	CO_2		
J. E. Baker	Millersville, OH	Rotary kiln	SO_2, CO, CO_2	1975	22
Allied Products	Alabaster, AL	Rotary kiln	PM, CO_2	1990	23
Allied Products	Alabaster, AL	Rotary kiln	PM, CO_2	1991	24
Dravo Lime	Saginaw, AL	Rotary kiln	PM, CO_2	1986	25

TABLE 4-1. (continued)

Company name	Plant location	Sources tested	Pollutants	Year	Ref.
Dravo Lime	Saginaw, AL	Rotary kiln	PM, SO_2, NO_x, CO_2	1991	26
Paul Lime Co.	Douglas, AZ	Rotary kiln	PM	1972	27
Bethlehem Mines	Annville, PA	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1974	28
Marblehead Lime	Gary, IN	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1974	29
Allied Products	Alabaster, AL	Rotary kiln	PM, CO_2	1974	30
J. E. Baker	Millersville, OH	Rotary kiln	PM	1975	31
Chemstar Lime Co.	Bancroft, ID	Six raw material processing sources	PM	1993	50
		Parallel flow regenerative kiln	PM, SO_2, NO_x, CO		

lists plant name, location, test date, sources tested, and pollutants measured for each of the primary references used to develop emission factors for this revision to Section 11.15. Table 4-2

TABLE 4-2. REFERENCES NOT USED TO DEVELOP EMISSION FACTORS

Reference No.	Reason for rejection
4	All test runs anisokinetic (140 to 190 percent).
32	Process rates labeled as incorrect.
33	Process rates labeled as incorrect.
34	Process data not included.
35	Test method, emission data units not specified.
36	Incomplete data, contradictory data.
37	Process data not included.
38	Process data not included.
39	Process data not included.
40	Process data not included.
41	Process data not included.
42	Process data not included.
43	All test runs anisokinetic (71, 87, 56, 135 percent).
44	Test data not provided.
45	Test data not provided.
46	All test runs anisokinetic (119 to 130 percent).
47	Process data not included.
48	Process data not included.
49	Test was not conducted on lime manufacturing source.

lists the references that were not used for this revision and indicates why emission factors were not developed from the data presented in those documents. Emission factors were developed for emissions of filterable PM, condensible inorganic PM, condensible organic PM, PM-10, CO, CO_2, SO_2, and NO_x. Table 4-3 summarizes the data presented in each of the reports from which emission factors were developed.

As has been the practice in previous versions of AP-42, the emission factors for lime kilns presented in Table 4-3 are in units of mass of pollutant emitted in kg (lb) per mass of lime produced in Mg (ton). Five of the 28 test reports from which lime kiln emission factors were developed provided process rates in terms of lime production; five reports provided process rates in terms of both stone feed and lime production; and the remaining 18 reports provided process rates on the basis of stone feed. Of the five reports that included both feed and production rates, the ratio of production to feed ranged from 0.38 to 0.55 and averaged 0.48. Therefore, a production-to-feed ratio of 0.5 was used to convert feed rates to production rates for those test reports for which only feed rates are provided.

Two of the test reports (References 15 and 19) provide data on emissions from atmospheric hydrators. Both of these reports provide feed and production data, and the emission factors are presented in Table 4-3 in units of mass of pollutant per mass of hydrated lime produced. Emission factors for the mechanical processing of limestone (crushing, screening, and grinding) are presented in Table 4-3 in units of mass of pollutant emitted per mass of stone feed.

Particle size data have not been revised from the previous version of AP-42 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 AP-42. A detailed discussion of how the particle size data were developed for the section can be found in Reference 1, which is the background report for the previous revision, dated October 1986. Table 4-4 summarizes the particle size data from Reference 1.

The following section describes each of the references used to develop emission factors for Section 11.15.

TABLE 4-3. SUMMARY OF TEST DATA FOR LIME MANUFACTURING

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (coal-fired)	None	PM, filterable	5	130-200 (270-410)	170 (330)	A	6
Rotary kiln (coal-fired)	None	PM, filterable	16	110-300 (210-590)	190 (370)	A	7
Rotary kiln (coal-fired)	Large-diameter cyclone	PM, filterable	15	34-80 (68-160)	60 (120)	A	7
Rotary kiln (coal-fired)	Large- diameter cyclone	PM, filterable	2	97-110 (190-210)	100 (200)	C	8
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	12	0.026-0.072 (0.052-0.14)	0.049 (0.097)	A	7
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	3	0.23-0.31 (0.46-0.63)	0.28 (0.56)	C	28
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	6	0.23-0.70 (0.45-1.4)	0.41 (0.83)	D	17
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	2	0.55-0.56 (1.1)	0.55 (1.1)	D	3
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	6	0.64-1.5 (1.6-3.0)	0.98 (2.0)	D	16
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	3	0.41-0.63 (0.82-1.3)	0.51 (1.0)	D	18
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	2	0.070-0.10 (0.14-0.21)	0.087 (0.17)	C	15
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	3	0.12-0.13 (0.25)	0.13 (0.25)	B	26
Rotary kiln (coal-fired)	ESP	PM, filterable	16	2.1-6.1 (4.4-12.1)	4.3 (8.5)	A	7
Rotary kiln (coal-fired)[c]	Venturi scrubber	PM, filterable	3	0.30-0.51 (0.60-1.0)	0.46 (0.93)	D	31
Rotary kiln (coal-fired)[c]	Venturi scrubber	PM, filterable	3	2.4-6.5 (4.7-13)	4.1 (8.2)	C	11
Rotary kiln (coal-fired)[d]	Venturi scrubber	PM, filterable	3	1.8-2.3 (3.5-4.7)	2.0 (4.0)	C	10
Rotary kiln (coal-fired)[d]	Venturi scrubber	PM, filterable	3	1.1-1.2 (2.2-2.5)	1.2 (2.4)	B	5
Rotary kiln (coal-fired)	Venturi scrubber	PM, filterable	3	0.47-0.64 (0.94-1.3)	0.55 (1.1)	B	24
Rotary kiln (coal-fired)[e]	Venturi scrubber	PM, filterable	3	0.35-0.50 (0.71-1.0)	0.41 (0.82)	B	23
Rotary kiln (coal-fired)	None	PM, condensible inorganic	3	0.57-1.5 (1.1-2.9)	0.90 (1.8)	C	6
Rotary kiln (coal-fired)	Large-diameter cyclone	PM, condensible inorganic	2	0.30-0.57 (0.61-1.1)	0.43 (0.87)	C	8
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	2	0.077-0.080 (0.16-0.16)	0.079 (0.16)	C	15

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	3	0.032-.039 (0.064-0.079)	0.035 (0.070)	C	28
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	6	0.13-0.38 (0.25-0.75)	0.22 (0.45)	D	16
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	3	0.026-0.10 (0.052-0.21)	0.058 (0.12)	D	18
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	6	0.067-1.4 (0.13-2.8)	0.45 (0.90)	D	17
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	2	0.14-0.18 (0.29-0.36)	0.16 (0.33)	D	3
Rotary kiln (coal-fired)[d]	Venturi scrubber	PM, condensible inorganic	3	0.027-0.20 (0.054-0.40)	0.12 (0.24)	B	5
Rotary kiln (coal-fired)[d]	Venturi scrubber	PM, condensible inorganic	3	0.20-0.47 (0.39-0.93)	0.33 (0.65)	C	10
Rotary kiln (coal-fired)[c]	Venturi scrubber	PM, condensible inorganic	3	0.030-0.090 (0.059-0.18)	0.055 (0.11)	C	11
Rotary kiln (coal-fired)[c]	Venturi scrubber	PM, condensible inorganic	3	0.20-0.27 (0.41-0.54)	0.24 (0.48)	D	31
Rotary kiln (coal-fired)	None	PM, condensible organic	3	0.32-0.81 (0.63-1.6)	0.51 (1.0)	C	6
Rotary kiln (coal-fired)[d]	None	PM, filterable and condensible inorganic	3	100-160 (200-330)	120 (250)	C	5
Rotary kiln (coal-fired)	None	SO_2	5	1.1-3.1 (2.2-6.2)	2.3 (4.6)	B	15
Rotary kiln (coal-fired)	None	SO_2	3	2.7-3.8 (4.3-7.7)	3.1 (6.2)	A	6
Rotary kiln (coal-fired)	Fabric filter	SO_2	3	0.11-0.26 (0.22-0.51)	0.18 (0.37)	C	28
Rotary kiln (coal-fired)	Fabric filter	SO_2	5	1.1-3.1 (2.2-6.2)	2.3 (4.6)	B	15
Rotary kiln (coal-fired)	Fabric filter	SO_2	1[f]	5.3 (11)	5.3 (11)	D	15
Rotary kiln (coal-fired)	Fabric filter	SO_2	3	0.0044-0.0066 (0.0087-0.011)	0.0066 (0.013)	B	26
Rotary kiln (coal-fired)[d]	Venturi scrubber	SO_2	3	0.25-0.65 (0.50-1.3)	0.40 (0.79)	C	10

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (coal-fired)[c]	Venturi scrubber	SO_2	3	15-19 (30-38)	17 (34)	D	11
Rotary kiln (coal-fired)[d]	Settling chamber	SO_2	6	2.1-9.2 (4.2-18)	5.8 (12)	C	22
Rotary kiln (coal-fired)[d]	Settling chamber/wet scrubber	SO_2	5	0.049-0.20 (0.10-0.40)	0.076 (0.15)	B	22
Rotary kiln (coal-fired)[c]	Settling chamber/wet scrubber	SO_2	6	0.17-0.30 (0.33-0.64)	0.23 (0.45)	B	22
Rotary kiln (coal-fired)[c]	Settling chamber	SO_2	6	5.2-6.6 (10-13)	5.9 (12)	C	22
Rotary kiln (coal-fired)	None	NO_x	3	0.20-1.0 (0.40-2.0)	0.56 (1.1)	A	8
Rotary kiln (coal-fired)	None	NO_x	12	0.73-2.3 (1.5-4.5)	1.6 (3.2)	A	6
Rotary kiln (coal-fired)	Fabric filter	NO_x	3	1.7-2.0 (3.3-3.6)	1.8 (3.6)	C	28
Rotary kiln (coal-fired)	Fabric filter	NO_x	23	2.0-3.5 (4.0-7.0)	2.7 (5.3)	B	15
Rotary kiln (coal-fired)	Fabric filter	NO_x	3	1.0-1.1 (2.0-2.2)	1.1 (2.1)	B	26
Rotary kiln (coal-fired)	None	CO	2	25-27 (50-54)	26 (52)	D	6
Rotary kiln (coal-fired)	Fabric filter	CO	4	0.11-0.83 (0.22-1.7)	0.38 (0.76)	B	15
Rotary kiln (coal-fired)	Fabric filter	CO	3	0.046-0.088 (0.093-0.18)	0.061 (0.12)	D	28
Rotary kiln (coal-fired)[d]	Settling chamber/ wet scrubber	CO	8	0.53-4.0 (1.1-8.1)	1.4 (2.7)	C	22
Rotary kiln (coal-fired)[c]	Settling chamber	CO	4	0.25-0.55 (0.49-1.1)	0.45 (0.90)	C	22
Rotary kiln (coal-fired)	None	CO_2	2	2,200-2,200 (4,500-4,500)	2,200 (4,500)	C	8
Rotary kiln (coal-fired)[d]	None	CO_2	1	2,100-2,800 (4,300-5,500)	2,500 (4,900)	C	5
Rotary kiln (coal-fired)	None	CO_2	5	710-1,500 (1,400-3,000)	1,300 (2,500)	A	6
Rotary kiln (coal-fired)	Fabric filter	CO_2	3	1,200-1,300 (2,400-2,700)	1,300 (2,500)	C	28
Rotary kiln (coal-fired)	Fabric filter	CO_2	3	not available	1,500 (3,100)	C	18
Rotary kiln (coal-fired)	Fabric filter	CO_2	3	not available	970 (1,900)	D	17
Rotary kiln (coal-fired)	Fabric filter	CO_2	2	1,100-1,100 (2,100-2,200)	1,100 (2,200)	C	15

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (coal-fired)	Fabric filter	CO_2	6	1,500-1,600 (3,100-3,300)	1,600 (3,200)	D	16
Rotary kiln (coal-fired)	Fabric filter	CO_2	3	1,400-1,500 (2,700-3,100)	1,500 (3,000)	B	26
Rotary kiln (coal-fired)	Venturi scrubber	CO_2	3	1,600-1,800 (3,200-3,600)	1,700 (3,400)	B	24
Rotary kiln (coal-fired)[e]	Venturi scrubber	CO_2	3	1,400-1,500 (2,900-3,000)	1,500 (3,000)	B	23
Rotary kiln (coal-fired)[d]	Venturi scrubber	CO_2	1	2,500 (4,900)	2,500 (4,900)	B	5
Rotary kiln (coal-fired)[d]	Venturi scrubber	CO_2	3	2,300-2,600 (4,600-5,200)	2,500 (5,000)	C	10
Rotary kiln (coal-fired)[c]	Settling chamber	CO_2	4	1,100-1,700 (2,100-3,400)	1,400 (2,700)	B	22
Rotary kiln (coal-fired)	Settling chamber	CO_2	10	360-1,300 (730-2,500)	940 (1,900)	B	21
Rotary kiln (coal-fired)[d]	Settling chamber/wet scrubber	CO_2	4	1,900-2,300 (3,900-4,600)	2,100 (4,200)	B	22
Rotary kiln (coal-fired)[d]	Settling chamber	CO_2	5	1,700 (3,300-3,400)	1,700 (3,400)	B	22
Rotary kiln (coal-fired)[d]	Venturi scrubber	SO_3	3	0.10-0.12 (0.20-0.24)	0.11 (0.21)	C	10
Rotary kiln (gas-fired)	ESP	PM, filterable	2	0.059-0.11 (0.12-0.22)	0.086 (0.17)	C	9
Rotary kiln (gas-fired)	Gravel bed filter	PM, filterable	3	0.38-0.50 (0.76-1.0)	0.44 (0.87)	C	12
Rotary kiln (gas-fired)	Gravel bed filter	PM, filterable	2	0.56-0.58 (1.1-1.2)	0.57 (1.1)	D	27
Rotary kiln (gas-fired)	ESP	PM, condensible inorganic	2	0.085-0.13 (0.17-0.27)	0.11 (0.22)	C	9
Rotary kiln (gas-fired)	Gravel bed filter	PM, condensible inorganic	3	0.0036-0.051 (0.0072-0.10)	0.022 (0.045)	D	12
Rotary kiln (gas-fired)	Gravel bed filter	PM, condensible inorganic	2	0.45-0.46 (0.90-0.92)	0.46 (0.91)	D	27
Rotary kiln (gas-fired)	ESP	NO_x	3	1.4-2.1 (2.8-4.2)	1.7 (3.5)	C	9
Rotary kiln (gas-fired)	ESP	CO	3	0.29-2.6 (0.59-5.1)	1.1 (2.2)	C	9
Rotary kiln (50/50 coal-, gas-fired)[e]	None	PM, filterable	2	24-56 (48-110)	40 (80)	D	30

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	PM, filterable	3	0.35-0.48 (0.69-0.97)	0.44 (0.87)	B	14
Rotary kiln (50/50 coal-, gas-fired)[e]	Venturi scrubber	PM, filterable	3	0.24-0.37 (0.49-0.74)	0.33 (0.65)	D	30
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	PM, condensible inorganic	3	0.032-0.051 (0.064-0.10)	0.041 (0.082)	B	14
Rotary kiln (60% coal-, 40% gas-fired)	None	SO_2	1[g]	1.4-2.7 (2.0-5.5)	1.9 (3.9)	D	14
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	NO_x	3	1.2-1.6 (2.3-3.2)	1.4 (2.7)	B	14
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	CO	3	0.14-0.82 (0.28-1.6)	0.41 (0.83)	B	14
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	CO_2	3	1,600-1,600 (3,200-3,300)	1,600 (3,200)	B	14
Rotary kiln (50/50 coal-, gas-fired)[e]	Venturi scrubber	CO_2	1	690 (1,400)	690 (1,400)	D	30
Rotary kiln (70% coke-, 30% coal-fired)	Venturi scrubber	PM, filterable	3	0.81-0.86 (1.6-1.7)	0.83 (1.7)	B	25
Rotary kiln (70% coke-, 30% coal-fired)	Venturi scrubber	CO_2	3	1,500-1,600 (3,000-3,200)	1,500 (3,000)	B	25
Rotary kiln with preheater (coal-fired)	Multiclone	PM, filterable	2	19-65 (38-130)	42 (84)	C	8
Rotary kiln with preheater (coal-fired)	Gravel bed filter	PM, filterable	3	0.57-0.61 (1.1-1.2)	0.59 (1.2)	C	13
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	PM, filterable	6	0.30-0.72 (0.61-1.4)	0.56 (1.1)	C	29
Rotary kiln with preheater (coal-fired)	Multiclone	PM, condensible inorganic	2	0.039-0.042 (0.078-0.083)	0.040 (0.081)	C	8
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	PM, condensible inorganic	6	0.40-0.68 (0.79-1.4)	0.57 (1.1)	C	29
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	PM, condensible organic	6	0.0099-0.14 (0.020-0.27)	0.076 (0.15)	C	29

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln with preheater (coal-fired)	Gravel bed filter	SO_2	2	0.026-0.63 (0.052-1.3)	0.33 (0.65)	C	13
Rotary kiln with preheater (coal-fired)	Settling chamber/ fabric filter	SO_2	6	1.2-2.8 (2.4-5.6)	1.9 (3.9)	C	21
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	SO_2	6	3.0-3.9 (6.0-7.8)	3.2 (6.4)	C	29
Rotary kiln with preheater (coal-fired)	None	NO_x	3	2.2-2.3 (4.4-4.6)	2.3 (4.5)	A	8
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	NO_x	12	0.83-2.3 (1.7-4.5)	1.1 (2.2)	C	29
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	CO	3	0.24-8.7 (0.48-17)	3.2 (6.3)	D	29
Rotary kiln with preheater (coal-fired)	None	CO_2	2	1,400-1,400 (2,800-2,800)	1,400 (2,800)	C	8
Rotary kiln with preheater (coal-fired)	Gravel bed filter	CO_2	2	2,500-2,600 (4,900-5,300)	2,500 (5,100)	C	13
Rotary kiln with preheater (coal-fired)	Settling chamber	CO_2	8	1,100-2,200 (2,100-4,300)	1,600 (3,200)	B	21
Rotary kiln with preheater (coal-fired)	Settling chamber	CO_2	7	600-1,100 (1,200-2,300)	840 (1,700)	B	21
Rotary kiln with preheater (coal-fired)	Settling chamber/ fabric filter	CO_2	3	1,100-1,200 (2,200-2,400)	1,100 (2,300)	B	21
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	CO_2	6	1,600-1,900 (3,200-3,800)	1,700 (3,400)	C	29
Calcimatic kiln (gas-fired)	None	PM, filterable	2	83-92 (170-190)	88 (180)	D	20
Calcimatic kiln (gas-fired)	None	PM, filterable	2	6.8-7.0 (14-14)	7 (14)	D	20
Calcimatic kiln (gas-fired)	None	PM, condensible inorganic	2	0.036-0.10 (0.072-0.19)	0.066 (0.13)	D	20
Calcimatic kiln (gas-fired)	None	PM, condensible inorganic	2	0.18-0.23 (0.37-0.46)	0.21 (0.41)	C	20
Calcimatic kiln (gas-fired)	None	NO_x	5	0.039-0.095 (0.079-0.19)	0.076 (0.15)	A	20

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Calcimatic kiln (gas-fired)	None	CO_2	2	2,000 (4,000-4,100)	2,000 (4,000)	C	20
Calcimatic kiln (gas-fired)	None	CO_2	2	670-690 (1,300-1,400)	680 (1,400)	C	20
Parallel flow regenerative kiln (gas-fired)	Fabric filter	PM, filterable	3	0.022-0.028 (0.044-0.056)	0.026 (0.051)	A	50
Parallel flow regenerative kiln (gas-fired)	Fabric filter	SO_2	3	0.00040-0.00080 (0.00079-0.0016)	0.00060 (0.0012)	A	50
Parallel flow regenerative kiln (gas-fired)	Fabric filter	NO_x	3	0.11-0.12 (0.22-0.24)	0.12 (0.024)	A	50
Parallel flow regenerative kiln (gas-fired)	Fabric filter	CO	3	0.21-0.24 (0.41-0.48)	0.23 (0.45)	A	50
Atmospheric hydrator	Wet scrubber	PM, filterable	2	0.026-0.043 (0.052-0.086)	0.033 (0.067)	B	19
Atmospheric hydrator	Wet scrubber	PM, filterable	3	0.066-0.17 (0.13-0.35)	0.087 (0.17)	C	15
Atmospheric hydrator	Wet scrubber	PM, condensible inorganic	2	0.0046-0.0091 (0.0091-0.018)	0.0067 (0.013)	B	19
Atmospheric hydrator	Wet scrubber	PM, condensible inorganic	3	0.010-0.079 (0.0071-0.021)	0.0069 (0.014)	C	15
Cooler	None	PM, filterable	2	2.4-4.5 (4.7-9.0)	3.4 (6.8)	C	20
Cooler	None	PM, condensible inorganic	2	0.0049-0.018 (0.010-0.036)	0.011 (0.023)	C	20
Cooler	None	CO_2	2	3.8-4.0 (7.6-8.0)	3.9 (7.8)	C	20
Final sizing screens	Fabric filter	PM, filterable	1	0.0012 (0.0023)	0.0012 (0.0023)	unrated	2
Primary crusher	None	PM, filterable	2	0.0076-0.0090 (0.015-0.0018)	0.0083 (0.017)	C	2
Primary crusher, screen, and hammermill	Fabric filter	PM, filterable	2	0.00020-0.00069 (0.00040-0.0014)	0.00044 (0.00089)	C	2
Scalping screen and hammermill	None	PM, filterable	2	0.00029-0.62 (0.00058-1.2)	0.31 (0.62)	D	2
Primary crushing[h]	Fabric filter	PM, filterable	3	0.00019-0.00023 (0.00039-0.00046)	0.00021 (0.00043)	A	50
Primary screening[i]	Fabric filter	PM, filterable	3	0.00027-0.00034 (0.00054-0.00067)	0.00030 (0.00061)	A	50

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Crushed material conveyor transfer[j]	Fabric filter	PM, filterable	6	$(2.8 \times 10^{-5}$-$8.1 \times 10^{-5})$ $(5.6 \times 10^{-5}$-0.00016)	4.4×10^{-5} (8.8×10^{-5})	A	50
Secondary and tertiary screening[k]	Fabric filter	PM, filterable	3	4.8×10^{-5}-4.0×10^{-5} $(9.5 \times 10^{-5}$-0.00016)	6.5×10^{-5} (0.00013)	A	50
Material transfer and drop points	None	PM, filterable	16	0.54-1.7 (1.1-3.3)	1.1 (2.2)	C	7
Fugitive, product loading (enclosed truck)	None	PM, filterable	3	0.15-0.41 (0.30-0.82)	0.31 (0.61)	A	7
Fugitive, product loading (open truck)	None	PM, filterable	2	0.67-0.84 (1.3-1.7)	0.75 (1.50)	B	7

[a]Filterable PM is that PM collected on or prior to the filter for an EPA Method 5 (or equivalent) sampling train. Condensible PM is that PM collected in the impinger portion of a PM sampling train and analyzed by EPA Method 202. Emission factors for condensible PM include both organic and inorganic condensible PM. Total PM is that PM collected in the entire sampling train and analyzed by Methods 5 and 202.

[b]Emission factors for kilns, coolers, preheaters, and hydrators in units of mass of pollutant emitted per mass of lime produced; emission factors for crushing, screening, grinding, and loading in units of mass of pollutant emitted per mass of stone/lime feed.

[c]Tests conducted on the this kiln are also documented in other references as indicated.

[d]Tests conducted on the this kiln are also documented in other references as indicated.

[e]Tests conducted on the this kiln are also documented in other references as indicated.

[f]Multiple CEM readings.

[g]A total of 30 CEM readings over a 4-hour period.

[h]Includes scalping screen, scalping screen discharges, primary crusher, primary crusher discharges, and ore discharge.

[i]Includes primary screening, including the screen feed, screen discharge, and surge bin discharge.

[j]Based on average of three runs each of emissions from two conveyor transfer points on the conveyor from the primary crusher to the primary stockpile.

[k]Based on sum of emissions from two emission points that include conveyor transfer point for the primary stockpile underflow to the secondary screen, secondary screen, tertiary screen, and tertiary screen discharge.

TABLE 4-4. AVERAGE PARTICLE SIZE DISTRIBUTION FOR ROTARY LIME KILNS[a]

Particle size, μm	Cumulative mass percent less than stated particle size			
	Uncontrolled rotary kiln	Rotary kiln with multiclone	Rotary kiln with ESP	Rotary kiln with fabric filter
2.5	1.4	6.1	14	27
5.0	2.9	9.8	ND	ND
10.0	12	16	50	55
15.0	31	23	62	73
20.0	ND	31	ND	ND

ND = no data available.
[a]Reference 1, Table 4-28; based on A- and C-rated particle size data.

4.2.1 Review of Specific Data Sets

4.2.1.1 Reference 1. Reference 1 is the background report used for the 1986 revision to the AP-42 section on lime manufacturing. Reference 1 documents the development of filterable PM emission factors and particle size distribution for various lime manufacturing sources. All of the primary sources used to develop the PM emission factors presented in Reference 1 were used in this proposed revision to update the filterable PM emission factors. The particle size data presented in Reference 1 were retained without change in this revision to AP-42.

4.2.1.2 Reference 2. This report documents measurements of controlled and uncontrolled filterable PM, condensible inorganic PM, and condensible organic PM emissions from limestone crushing operations. The sources tested included a primary crusher, final sizing screens, and a combination of scalping screens and a hammermill. The tests were conducted in 1974 and were sponsored by EPA as part of the information-gathering effort for an NSPS for stone crushing. Emissions from the primary crusher, scalping screens, and hammermill are controlled with a common fabric filter. Emissions from the final sizing screens are controlled with a separate fabric filter.

Method 5 (front and back halves) was used to measure PM emissions. Although back half PM catches are reported in the results, these processes operate at ambient temperature and should not emit condensible PM. Therefore, it is assumed that the back half catches are the result of an anomaly in the sampling and analytical procedures used. The test report does not include adequate information to determine the origin of this apparent anomaly.

Three runs were conducted on the outlets of the two fabric filters, but only two inlet runs were conducted. Several problems with the tests were reported. The final sizing screen fabric filter outlet data were discarded because the outlet flow rate was measured to be twice the inlet flow rate. Negative filter weights were reported for one of the runs on the primary crusher/scalping screens/hammermill fabric filter outlet and for two of the runs on the final sizing screen fabric filter outlet. In addition, for the test on the scalping screen/hammermill fabric filter outlet, emission rates varied by more than three orders of magnitude. Emission factors were developed for filterable PM emissions from all of the sources tested.

The emission factors for uncontrolled emissions from the primary crusher are rated C because only two test runs were conducted, and the emission factors for uncontrolled emissions from the scalping screens/hammermill are rated D because only two runs were conducted and the filterable PM data varied by more than three orders of magnitude. The emission factors for controlled emissions from the combination of primary crusher, scalping screens, and hammermill are rated C because only two runs were valid. The filterable PM emission factor for controlled emissions from the final sizing screens is unrated because only one test run was valid.

4.2.1.3 Reference 3. This report documents measurements of controlled PM emissions from three rotary kilns. The tests were conducted in July 1975 to supplement a compliance test sponsored by the Pennsylvania Department of Environmental Resources. Process rates were provided on the basis of lime production.

Particulate matter emissions from these kilns were controlled by two common fabric filters that comprised six compartments each. The fabric filters were arranged in parallel so that the emissions from the three kilns were routed simultaneously to both fabric filters. The emissions were sampled in one of the six compartments of each fabric filter. The emission data from each of the two compartments that were sampled were multiplied by a factor of six to obtain an estimate of total emissions from each fabric filter. Two test runs were conducted, and filterable and condensible inorganic PM emissions were measured. Emission factors were developed for controlled filterable PM and condensible inorganic PM emissions.

The data in this report were rated D. The test report generally was lacking in documentation, and the test method was not specified. Furthermore, only two test runs were conducted, and only one compartment of each fabric filter was sampled.

4.2.1.4 Reference 5. This report documents measurements of controlled PM and CO_2 emissions from a coal-fired rotary lime kiln. Particulate emissions from the kiln were controlled by a venturi scrubber. The tests were performed in February 1975 to determine whether particulate emissions from the kiln were in compliance with State regulations.

Process information was limited. Feed and production rates were not available for each test run, but the average feed rate was provided. Therefore, the emission factors are based on the average feed rate. In developing emission factors from the data, it was assumed that production rates were one-half of feed rates.

Three runs were conducted at both the inlet and outlet of the venturi scrubber. The sampling generally was in accordance with Method 5. However, the inlet sampling train was modified by placing the glass fiber filter behind the impingers. Both the impinger and filter contents were dried at 110°C (230°F) and weighed to determine the weight of the PM catch. Therefore, the measured inlet PM emission rate consists of both filterable and condensible inorganic PM emission rates. The outlet sampling train was in accordance with EPA Method 5. Orsat was used to make one measurement of CO_2 concentrations in the exhaust at both the inlet and outlet of the venturi scrubber.

From the inlet PM data, emission factors were developed for combined filterable and condensible inorganic PM. The outlet PM data were used to develop emission factors for controlled filterable PM and condensible inorganic PM emissions. In addition, an emission factor was developed for CO_2 emissions.

A rating of C was assigned to the inlet PM data because the tests conducted at the inlet varied significantly from standard sampling protocol. The outlet data were rated B because standard sampling protocol was followed. The test methods were sound and no problems were reported, but the report lacked adequate process documentation to warrant a higher rating. The CO_2 data are rated C because only two measurement were made.

4.2.1.5 Reference 6. This report documents measurements of filterable PM, condensible inorganic PM, condensible organic PM, CO, SO_2, NO_x, and particle size distribution on a coal-fired rotary lime kiln. In addition, data on CO_2 emissions were generated from the PM sampling runs. At the time of the test, the kiln was not equipped with emission control equipment. The test was conducted from April 29 to May 3, 1975 and was sponsored by EPA.

Process rates for this test are provided on the basis of feed rate. However, the report states that historical data from the facility showed that for every two tons of feed, one ton of product was produced. Therefore, a feed to production ratio of 0.5 was used to develop emission factors on the basis of lime production.

The following test methods were used: Method 5 for filterable PM, Method 10 for CO, Method 6 for SO_2, Method 7 for NO_x, and a Brink impactor for particle size emissions data. The back half of the Method 5 sampling train also was analyzed for condensible PM. The analysis included an ether-chloroform extraction to quantify condensible organic emissions. However, the analytical procedures were not described in detail. Five runs were originally conducted to determine PM emissions, but two of these were not completed due to sampling difficulties. These two runs, however, provided complete CO_2 analyses. Thus, data from all five tests were used to determine average CO_2 emissions. Because of unidentified problems with the analyzer, CO emission data are reported for only two of the five runs, and the results of the two runs reported are suspect.

As stated previously, the particle size data in Reference 6 were evaluated for the 1986 update of AP-42 Section 11.15 and were not reevaluated as part of this revision. However, the particle size data were used to develop the PM-10 emission factors presented in this revision to Section 11.15. Only two of the PM runs included an analysis of the back half of the Method 5 sampling train.

The sampling and analytical methods for filterable PM, SO_2, and NO_x followed EPA procedures, and sufficient data and documentation are presented for adequate validation. Data for the filterable PM, SO_2, and NO_x from this reference were assigned an A rating because the sampling and analysis methods were sound, and the documentation was adequate. Because the Method 5 back-half analysis lacked sufficient documentation, the condensible inorganic and organic PM data are rated C. Due to the problems with the CO test, the CO data are rated D.

As discussed in Reference 1, the Brink impactor, which was used to collect the particle size data, is not well suited for sampling uncontrolled emissions that are characterized by substantial quantities of large particles. In addition, the cutpoint of the inertial impactor was not calibrated. Therefore, the particle size data are rated C.

4.2.1.6 Reference 7. This test report documents measurements of controlled and uncontrolled PM emissions from two rotary kilns. The emissions from one kiln (Kiln 6) were controlled by a combination of a cyclone and a fabric filter, and the emissions from the second kiln (Kiln 7) were controlled by an ESP. Uncontrolled PM emissions from a dust collection system also were measured. The dust collection system consists of several hoods located over conveyor transfer and drop points. Particulate matter emissions are collected in the hoods and ducted to a common fabric filter. In addition, fugitive PM emissions were tested at two product loading areas. The tests were sponsored by EPA and conducted from October 15, 1980 through January 12, 1981. The results of analyses for total PM and particle size distributions are presented for all sampling locations. Process rates were provided on the basis of lime production.

Sampling of the two kilns was conducted in accordance with EPA Method 5. Fifteen runs were conducted on Kiln 6 at the fabric filter inlet, downstream of the cyclone, and 12 runs were conducted at the fabric filter outlet. Sixteen runs were conducted on Kiln 7 at both the inlet and outlet of the ESP. Particle size was measured using a cascade impactor with a cyclone preseparator.

Emissions from the dust collection system also were sampled in accordance with EPA Method 5. The emission factors were reported as total PM emissions per ton of product. Fifteen test runs were conducted on a central dust collection duct, which transports dust collected at 13 product transfer and drop points to a fabric filter. The inlet and outlet to the fabric filter were not tested because dust collected from other product operations also was ducted to the fabric filter. The report does not provide details on the design of the collection system. Therefore, it is not possible to determine the capture efficiency of the hoods or to determine if face air velocities for the hoods are typical. As a result, it is not possible to determine if the test results are typical, biased high due to induced wind erosion by the ventilation system, or biased low due to poor capture efficiency.

Fugitive PM emissions from two product loading bays also were measured. Five test runs for total suspended particulates (< 30μ), inhalable particulates (< 15μ), and fine particulates (< 2.5μ) were conducted during product loading operations using a standard high volume air sampler (Hi-Vol), two Hi-Vols with Andersen size-selective inlet (SSI) devices, and two Hi-Vols with cyclones and impactors. Two of the runs were conducted on open trucks, and three runs were conducted on enclosed trucks. Background PM concentrations were tested using a Hi-Vol, a Hi-Vol with an SSI and a Hi-Vol with a cyclone and an impactor.

The PM emission and particle size data for the tests on the kilns were rated A because standard sampling protocol was followed and no problems were reported. The PM emission data for product transfer and drop points are rated C due to the uncertainty in the representativeness of the data, as explained previously. The emission data for loading enclosed trucks also are rated A; the emission data for loading open trucks are rated B because only two runs were conducted.

4.2.1.7 Reference 8. This test was conducted on the exhaust of two coal-fired rotary kilns to measure uncontrolled emissions of PM and NO_x and to obtain particle size data. The test was conducted in December 1975 and was sponsored by EPA. Process rates were provided on the basis of both stone feed and lime production.

The sampling locations for each kiln were located downstream of a cyclone and upstream of a fabric filter. At each location, two runs were conducted to measure filterable PM, condensible inorganic PM, and CO_2 emissions, and three runs to quantify emissions of NO_x. Method 5 was used to measure PM emissions, and Method 7 was used to quantify emissions of NO_x. Carbon dioxide concentrations in the exhaust stream were measured using Orsat, and cascade impactors were used for the particle size determination.

This emission test is well documented, and sampling and analytical methods follow EPA protocol. However, because only two runs were conducted at each sampling location, the PM and CO_2 data were rated C. The data for NO_x emissions are rated A. The particle size data are rated D because only a single test run was conducted on each kiln.

4.2.1.8 Reference 9. This report documents measurements of PM, CO, SO_2, NO_x, and CO_2 emissions from three natural gas-fired rotary kilns equipped with ESP's. The emission test was sponsored by EPA to provide information for establishing an NSPS for lime kilns. The test was conducted from April 30 to May 3, 1974.

Emissions from the three kilns feed into a common plenum that is designed to distribute the exhaust gas evenly to a pair of ESP's. During the test, one of the kilns was not operating. The outlet of each ESP is ducted to a separate stack, from which all samples were taken. The north stack was tested for filterable and condensible PM, CO, and SO_2 emissions using Methods 5, 10, and 6, respectively; the south stack was tested for filterable and condensible PM, CO, and NO_x emissions by Methods 5, 10, and 7, respectively. The Method 6 sampling train was modified by adding a dry impinger between the isopropanol bubbler and the first peroxide impinger. Carbon dioxide concentrations were measured by Orsat. Three runs were conducted on each stack.

The results of the first PM run were not valid because the probe was improperly positioned during sampling. The third Method 10 run on both stacks indicated CO concentrations that were 5 to 10 times the concentrations recorded during the first two runs. No explanation for this inconsistency in the CO emission data is provided in the report. Finally, all CO_2 readings are reported as invalid due to system leaks.

Emission factors were developed for filterable PM, condensible inorganic PM, CO, and NO_x emissions. Emission factors were not developed for CO_2 due to the problem noted above. In addition, emission factors were not developed for SO_2 emissions because SO_2 was not detected in any of the samples collected. Process rates are provided in the report on the basis of raw material feed. The emission factors developed from the data are presented in units of mass of pollutant emitted per mass of product, based on the assumption that production rates are one-half of feed rates.

The PM data are rated C because they are based on only two test runs and estimated production rates. The CO data are rated C because of the inconsistency in emission rates. The NO_x data are rated C because only one of two stacks was tested, and the total emission rate was assumed to be twice the emission rate from the single stack that was tested.

4.2.1.9 Reference 10. This test report documents measurements of PM, SO_2, and CO_2 from a coal-fired rotary kiln and a cooler. The tests were conducted from May 21 to 23, 1974 by the facility as part of a self-evaluation. Process rates are provided on the basis of both stone feed and lime production.

The exhaust from a product cooler was ducted to one of the stacks tested. Because the test report did not specify how much of the exhaust was recovered for kiln combustion gas, an emission factor for this source could not be determined.

Three runs were performed to determine filterable and condensible inorganic PM, CO_2, and SO_2 emissions from the kiln. Test methods followed EPA protocol, but the report did not present raw field or laboratory data, and the exact sampling locations were not specified. Because of the general lack of documentation, the data from this reference were rated C.

4.2.1.10 Reference 11. This test report documents measurements of PM, SO_2, and CO_2 emissions from a coal-fired rotary kiln. The test was conducted in April 1975 and was sponsored by the facility to analyze the exhaust of the venturi scrubber controlling emissions from the kiln. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate.

Three runs were performed at the scrubber outlet to determine emissions of filterable and condensible inorganic PM using Method 5 and emissions of SO_2 using Method 6. For the SO_2 test, only one run was conducted to determine stack gas flow rate. In addition, only a single CO_2 measurement was made.

The report contained no raw data, provided little information about the process, and did not specify the sampling location. For these reasons, the PM data from this report were rated C. The SO_2 data are rated D due to the lack of documentation and the fact that only one flow rate measurement was made during the test. Emission factors were not developed for CO_2 because only one CO_2 measurement was reported.

4.2.1.11 Reference 12. This test was conducted to measure controlled PM emissions from a gas-fired rotary kiln. The test was performed on June 6, 1973 as part of a compliance test for the State of Arizona.

Emissions from the kiln are controlled by a cyclone and gravel bed filter combination. Three runs were conducted on the gravel bed filter outlet using Method 5. However, the method for quantifying condensible inorganic PM emissions from the back half of the Method 5 sampling train is not described in the report.

Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate. Emission factors were developed for emissions of filterable and condensible inorganic PM.

The filterable PM data are rated C due to the general lack of adequate documentation in the report and the fact that production rates were estimated from feed rates. The condensible inorganic PM data are rated D because the method is not described and because of the wide range in data (the emission rate for Run 1 is reported as 13 times the emission rate for Run 3). It is unknown if the wide range in data is due to variations in emission rates or is due to problems with the test.

4.2.1.12 Reference 13. This test report documents measurements of controlled filterable PM and SO_2 emissions from a coal-fired rotary kiln. The tests were conducted on May 6 and 7, 1975 as part of a compliance test. Emissions from the kiln are controlled with a gravel bed filter.

Three test runs were performed at the gravel bed filter outlet to determine the controlled filterable PM emissions, and two runs were conducted to quantify SO_2 emissions. Filterable PM and SO_2 emissions were sampled using EPA Methods 5 and 6, respectively. Two measurements of CO_2 concentrations were taken using Orsat.

Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate. Emission factors were developed for emissions of filterable and condensible inorganic PM.

The filterable PM data are rated C due to the general lack of adequate documentation in the report and the fact that production rates were estimated from feed rates. The SO_2 and CO_2 emission data are also rated C for the same reasons and because only two runs were conducted.

4.2.1.13 Reference 14. This test report documents measurements of filterable and condensible PM, particle size distribution, CO, CO_2, SO_2, and NO_x emissions. The test was conducted on a coal- and gas-fired rotary kiln in September 1975. The test was sponsored by EPA to collect data to establish standards for new and substantially modified sources. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate.

The emissions from the kiln were controlled by a cyclone followed by a venturi scrubber. Method 5 was used to measure PM emissions, Method 6 was used to measure SO_2 emissions, NO_x emissions were quantified using Method 7, Method 10 was used to measure CO emissions, and CO_2 concentrations were measured using Orsat. A continuous emission monitor (CEM) also was used to take 30 measurements of SO_2 emissions over a 4-hour period. In addition, particle size was measured using a cascade impactor with cyclone preseparator.

The scrubber inlet was sampled for three test runs for particle size distribution and SO_2 concentrations. The outlet was sampled for three test runs for particle size distribution, filterable and condensible inorganic PM, CO, CO_2, and SO_2 emissions. Twelve samples were gathered at the outlet for the NO_x analysis.

The CEM data on inlet SO_2 emissions averaged 168 parts per million (ppm). However, with the exception of the first run on the inlet, all Method 6 SO_2 data indicated 0 ppm. As a result, the inlet Method 6 data were discarded because it was suspected that the SO_2 was reacting with lime particles on the filter at the front of the Method 6 sampling train. No explanation is given as to why this problem did not occur during the first inlet run. The outlet data for both the Method 6 train and the CEM indicated negligible SO_2 emissions.

The PM, NO_x, CO, and CO_2 data are rated B. The Method 6 SO_2 data are not rated because the results from only one run were valid. The CEM data for SO_2 emissions are rated D because they are based on a single gas flow rate measurement, and there is no evidence in the report that the instrument was certified. The particle size data are rated C because no measurements of mass loading were made at the scrubber inlet, and only two of the three outlet runs were valid because of impactor overloading.

4.2.1.14 Reference 15. This test report documents measurements of filterable and condensible inorganic PM, SO_2, NO_x, CO, and CO_2 emissions from a coal-fired rotary kiln and filterable and condensible inorganic PM emissions from an atmospheric hydrator. The report mentioned that the plant was switching its fuel from natural gas to coal during the first day of sampling, but did not elaborate on this change in process. The emissions from the kiln are controlled with a fabric filter. The tests were performed in September 1975 and were sponsored by EPA to collect data for setting standards on new and modified sources.

Process rates for the kiln are provided on the basis of lime production, and process rates for the hydrator are provided on the basis of both lime feed and hydrated lime production.

Emissions of PM, SO_2, NO_x, and CO were measured using Methods 5, 6, 7, and 10, respectively. Sulfur dioxide emissions also were measured by CEM. Carbon dioxide concentrations were measured using Orsat. Six SO_2 runs and four CO runs were conducted on the fabric filter inlet; six PM, six SO_2, and three NO_x runs were conducted on the outlet of the fabric filter. Four runs of the kiln PM test were slightly anisokinetic (111 to 118 percent). The first SO_2 sample at the inlet was discarded due to a non-steady-state process at the plant. All of the outlet SO_2 samples were below the detection limit. Three PM runs were conducted on the outlet of the wet scrubber controlling emissions from the atmospheric hydrator. Two of these runs also were reported as slightly anisokinetic (89 and 119 percent).

Emission factors were developed for emissions of filterable and condensible inorganic PM, SO_2, NO_x, CO, and CO_2 emissions from the kiln and for filterable and condensible inorganic PM emissions from the hydrator.

The PM data for both the kiln and hydrator are rated C because of the number of anisokinetic runs. The NO_x, CO, CO_2, and Method 6 SO_2 data are rated B. The methodologies were sound, and no significant problems were reported, but the report lacked adequate documentation for a higher rating. The CEM SO_2 data are rated D because only an average emission rate based on a single gas flow rate measurement is presented, and there is no evidence in the report that the instrument was certified.

4.2.1.15 References 16, 17, 18. These test reports were supplied by the National Lime Association as Exhibits 1, 2, and 3, respectively. The purpose of the tests were not specified, although each measured filterable and condensible inorganic PM emissions from coal-fired rotary kilns that were controlled with fabric filters. In two of the tests (References 16 and 18), new bags had been installed in the fabric filters prior to testing. The tests were conducted between May and August of 1977. In Reference 16, process rates are provided on the basis of both stone feed and lime production. In References 17 and 18, process rates were provided on the basis of feed, and production rates were estimated as half of the feed rate.

Each of the tests were conducted in a similar fashion. Filterable PM emissions were measured in a single fabric filter compartment using Method 5. Thus, emissions from the entire fabric filter were estimated by multiplying the emission rate for the compartment measured by the number of compartments. Two of the fabric filters (References 17 and 18) consisted of six compartments, and one of the fabric filters comprised 12 compartments. Details on the back-half analysis for condensible PM are not provided in the reports. In the tests documented in References 16 and 17, six PM runs were conducted, and in the test documented in Reference 18, three runs were conducted.

Carbon dioxide emissions were measured using Orsat. In Reference 16, two CO_2 emission measurements are reported, and in References 17 and 18 the average of three CO_2 emission measurements are reported.

Emission factors were developed for filterable and condensible inorganic PM emissions and for CO_2 emissions from rotary lime kilns. The PM data are rated D because emissions were measured in only 1 of 6 or 1 of 12 fabric filter compartments, and total emissions were estimated based on the assumption that emissions from all compartments were comparable. The CO_2 emission data from References 17 and 18 also are rated C for the same reason. The CO_2 emission data from Reference 16 were downrated to D because only two CO_2 emission measurements are reported.

4.2.1.16 Reference 19. This test report documents measurements of PM emissions from an atmospheric hydrator that is controlled with a medium-energy wet scrubber. The test was performed April 16 to 18, 1974 and was sponsored by EPA to obtain background data for developing an NSPS for lime manufacturing. Process rates were provided on the basis of both lime feed and hydrated lime production.

Method 5 was used to measure PM emissions, and three test runs were conducted. Run 2 of the test was slightly anisokinetic (115 percent). However, the results from Run 2 are comparable to the results of the other two runs. For the third run, a larger nozzle size was used to ensure that the run was isokinetic. Emission factors were developed for filterable and condensible inorganic PM emissions. Carbon dioxide concentrations in the exhaust were negligible.

The emission data are rated B. The methodology was sound, and no major problems were reported. However, because one of the runs was anisokinetic, an A rating was not warranted.

4.2.1.17 Reference 20. This test report documents measurements of PM and NO_x emissions from two calcimatic lime kilns (Kiln 1 and Kiln 2) and from a calcimatic lime kiln (Kiln 1) cooler. The kilns are fired with natural gas. The tests were performed in October 1975 and were sponsored by EPA as part of a data acquisition program. Process rates were provided on the basis of both stone feed and lime production.

The exhaust system for the kilns is designed to direct 95 percent of the exhaust from Cooler 1 to the exhaust duct serving Kiln 1; the remaining 5 percent of the exhaust from Cooler 1 is ducted to the exhaust duct serving Kiln 2. The exhaust from Kiln 1 was sampled downstream of the junction with the cooler exhaust duct. As a result, the measured emissions from Kiln 1 consist of the emissions from the kiln and approximately 95 percent of the cooler emissions. The measured emissions for Kiln 2 consist of the emissions from the kiln and approximately 5 percent of the cooler emissions.

Emissions from the kilns and from the cooler were sampled for uncontrolled filterable and condensible inorganic PM and CO_2 emissions. Method 5 was used to measure PM emissions, and CO_2 emissions were measured using Orsat. Two runs were conducted on each of the sources. In addition, the exhaust from Kiln 1 was tested for NO_x emissions. Five NO_x runs were conducted using Method 7.

Emission factors were developed for filterable and condensible inorganic PM, NO_x, and CO_2 emissions. In determining the PM and CO_2 emission factors for Kiln 1, 95 percent of the emissions from Cooler 1 were subtracted from the measured emission rate for the preheater; in determining the emission factors for Kiln 2, 5 percent of the emissions from Cooler 1 were subtracted from the measured emission rate for the preheater. The emission factor for NO_x emissions from Kiln 1 are based on the measured emissions only because NO_x emissions from the cooler were not measured. However, cooler NO_x emissions should have been negligible in comparison to the kiln NO_x emission rate.

The production rates for the kilns are comparable--Kiln 1 produces 182 Mg/day (200 tons/day) and Kiln 2 produces 227 Mg/day (250 tons/day). However, based on this emission test, the emission rate for Kiln 2 is more than an order of magnitude higher than the emission rate for Kiln 1. No explanation for this disparity is provided in the report.

The PM emission data for the kilns are rated D because only two runs were conducted and the exhaust system configuration precluded isolating kiln emissions from cooler emissions. The NO_x data for the kilns are rated C because only two runs were conducted and there is some uncertainty in the measured rate due to the contribution of the cooler to the exhaust stream sampled. The kiln CO_2 emission data and the cooler PM and CO_2 also are rated C because only two runs were conducted.

4.2.1.18 Reference 21. This test report documents measurements of CO_2 and SO_2 emissions from three coal-fired rotary lime kilns (Kilns 4, 5, and 6). The sulfur contents of the coal during the test ranged from 2.4 to 4 percent. The tests were conducted in January 1976 and were sponsored by EPA. The purpose of the tests was to collect data for an NSPS for lime manufacturing. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate.

The exhausts from the three kilns each pass through a settling chamber and into a common plenum that distributes the gases among the 22 compartments of a fabric filter. Two of the kilns (Kilns 4 and 5) were equipped with preheaters. An attempt was made to sample the fabric filter inlets. However, the three fabric filter inlet streams were very difficult to sample because buildup of lime particles in the sampling probe either choked the probe intake or neutralized the SO_2. As a result, only the fabric filter outlet was sampled.

Emissions of SO_2 were measured using Method 6, and a total of six runs were conducted. Concentrations of CO_2 were measured using Orsat. Nine CO_2 measurements were made on the Kiln 4 inlet, seven measurements on the Kiln 5 inlet, and eight measurements on the Kiln 6 inlet. Three CO_2 measurements were made on the combined fabric filter outlet for the three kilns. Emission factors were developed for SO_2 emissions from the combination of all three kilns and for CO_2 emissions from each of the three kilns.

The SO_2 data are rated C because they are based on an average flow rate measurement, and the data represent emissions from a combination of kilns, two of which had preheaters and one of which did not. The CO_2 data are rated B. The test methodology was sound, and no problems were reported. However, because production rates were estimated based on feed rates, a higher rating is not warranted.

4.2.1.19 Reference 22. This test report documents measurements of CO, CO_2, and SO_2 emissions from two coal-fired rotary kilns. Kiln 1 produces dolomitic lime, and Kiln 2 produces dead-burned dolomite. The sulfur content of the coal used during the test ranged from 2.70 to 3.74 percent. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate. Emissions from the kilns are controlled with venturi scrubbers. The tests were conducted from December 2 through 9, 1975 and were sponsored by EPA. The purpose of the tests was to gather information necessary to set performance standards for lime manufacturing.

The waste gas from each kiln is ducted to a separate cooler, settling chamber, and wet scrubber, and both the inlets and outlets of the scrubbers were sampled. Each sample was analyzed for CO, CO_2, and SO_2. Methods 1 and 2 were used to determine stack gas velocity. Method 2 was altered to account for cyclonic flow of the stack gas. The probe was first angled so that there was no pressure differential across the pitot tube. The probe was then rotated 90° and the pressure was measured.

Carbon dioxide concentrations were determined per Method 3 using Orsat. Sulfur dioxide concentrations were determined per Method 6 with the following modifications: (1) at the outlet locations, no glass wool filter was used in the sampling probe and (2) at the inlet locations a specially designed probe (shielded gas pickup ports) was used to decrease particle entrainment in the sample. Six uncontrolled SO_2 runs were conducted on each kiln, five controlled SO_2 runs were conducted on Kiln 1, and six controlled SO_2 runs were conducted on Kiln 2. Scrubber inlet flow rates were not measured, so the uncontrolled SO_2 emission rates were determined by estimating inlet flow rates based on the flow rates measured at the scrubber outlets. In addition, the scrubber outlet flow rates for three of the six runs on Kiln 2 were estimated based on the three runs for which flow rates were measured.

Carbon monoxide samples were gathered in accordance with Method 10 except that no ascarite scrubber was used to correct for CO_2 interference. The authors of this report suspect that the error is approximately + 10 to 15 ppm. Four CO runs were conducted on the Kiln 1 scrubber inlet and outlet, and two CO runs were conducted on the Kiln 2 scrubber inlet and outlet. The concentrations at the outlet were measured to be higher than the inlet concentrations.

Emission factors were developed for uncontrolled and controlled SO_2 emissions from kilns producing dolomitic lime and dead-burned dolomite. Emission factors also were developed for CO emissions from both kilns. For Kiln 1, the results of all eight runs (four inlet and four outlet) were averaged to produce a single CO emission factor. Similarly, for Kiln 2, the results of all four runs (two inlet and two outlet) were averaged to produce a single CO emission factor. Emission factors for CO_2 emissions were developed by the same procedure as the emission factors for CO.

The emission data for uncontrolled SO_2 emissions are rated C because they are based on estimated gas flow rates. The emission data for controlled SO_2 emissions are rated B. Although the methodology was sound, the report lacked adequate documentation to warrant an A rating. The CO_2 emission data also are rated B for the same reason. The CO emission data are rated C because of suspected CO_2 interference in the sampling and analysis.

4.2.1.20 Reference 23. This test report documents measurements of filterable PM and CO_2 emissions from a coal-fired rotary kiln. Emissions from the kiln are controlled with the combination of a multiclone and a venturi scrubber. The test was conducted in October 1990 to demonstrate compliance with State regulations. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate.

Method 5 was used to measure PM emissions, and CO_2 concentrations in the exhaust stream were measured using Orsat. Three test runs were conducted. Emission factors were developed for controlled filterable PM emissions and for CO_2 emissions from the kiln.

The emission data are rated B. Although the methodology was sound, the report lacked adequate documentation to warrant an A rating.

4.2.1.21 Reference 24. This test report documents measurements of filterable PM and CO_2 emissions from a different coal-fired rotary kiln located at the same facility as in Reference 23. Emissions from the kiln are controlled with the combination of a multiclone and a venturi scrubber. The test was conducted in October 1991 to demonstrate compliance with State regulations. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate.

Method 5 was used to measure PM emissions, and CO_2 concentrations in the exhaust stream were measured using Orsat. Three test runs were conducted. Emission factors were developed for controlled filterable PM emissions and for CO_2 emissions from the kiln.

The emission data are rated B. Although the methodology was sound, the report lacked adequate documentation to warrant an A rating.

4.2.1.22 Reference 25. This test report documents measurements of filterable PM and CO_2 emissions from a rotary kiln. The kiln was fired with a combination of 30 percent coal and 70 percent petroleum coke. Emissions from the kiln are controlled with the combination of a settling chamber, multiclone, and venturi scrubber. The test was conducted in October 1986 to demonstrate compliance with State regulations. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate.

Method 5 was used to measure PM emissions, and CO_2 concentrations in the exhaust stream were measured using Orsat. Three test runs were conducted. Emission factors were developed for controlled filterable PM emissions and for CO_2 emissions from the kiln.

The emission data are rated B. Although the methodology was sound, the report lacked adequate documentation to warrant an A rating.

4.2.1.23 Reference 26. This test report documents measurements of filterable PM, SO_2, NO_x, and CO_2 emissions from a different coal-fired rotary kiln located at the same facility as in Reference 25. Emissions from the kiln are controlled with the combination of a multiclone and a fabric filter. The test was conducted in July 1991 to demonstrate compliance with State regulations. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate.

Method 5 was used to measure PM emissions; NO_x emissions were quantified using Method 7E; Method 8 was used to measure SO_2 emissions; and CO_2 concentrations in the exhaust stream were measured using Orsat. Three test runs were conducted. Emission factors were developed for controlled filterable PM, NO_x, SO_2, and CO_2 emissions from the kiln.

The emission data are rated B. Although the methodology was sound, the report lacked adequate documentation to warrant an A rating.

4.2.1.24 Reference 27. This test report documents measurements of controlled filterable and condensible inorganic PM emissions from a gas-fired rotary kiln. The kiln was equipped with a gravel bed filter to control PM emissions. It is unclear from the report if the process rates specified are for feed or production. The test was conducted on September 20, 1972 following the change of filter media in the gravel bed filter.

Two test runs were performed in accordance with EPA Method 5, and no difficulties were noted. The sampling points were located downstream of the gravel bed filter, and filterable and condensible inorganic PM emissions were measured. Emission factors for filterable and condensible inorganic PM emissions were developed based on the assumption that the process rate provided was for kiln feed, because feed rate is more commonly reported than is production rate.

The emission factors developed in this reference were rated D. Only two test runs were conducted, process rates were not clearly described, and the test report lacked other documentation to warrant a higher rating.

4.2.1.25 Reference 28. This test report documents measurements of filterable and condensible inorganic PM, SO_2, NO_x, trace metals, and CO emissions from a coal-fired rotary lime kiln. Emissions from the kiln are controlled with a fabric filter. The sulfur content of the coal ranged from 0.5 to 1.5 percent. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate. The test was sponsored by EPA and was conducted in January 1974 to provide information for an NSPS for lime manufacturing.

Method 5 was used to measure PM emissions; Method 6 was used to measure SO_2 emissions; NO_x emissions were quantified using Method 7; Method 10 was used to measure CO emissions; and CO_2 concentrations in the exhaust stream were measured using Orsat. Three test runs were conducted. In addition, a trace metal analysis was performed on the PM catches for one run on two separate stacks.

Testing was conducted on the four stacks that serve the fabric filter. Two stacks were tested by an EPA contractor and the other two stacks were tested by the facility. Data for the two stacks tested by the facility were not available. The total plant emissions were estimated by doubling the emissions from the two stacks tested by the EPA contractor because the emission rates from the other stacks were considered to be comparable to the emission rates from the two stacks tested. Emission factors were developed for controlled filterable PM, NO_x, SO_2, CO, and CO_2 emissions from the kiln. The data were inadequate to develop trace metal emission factors.

The emission data are rated C. The methodology was sound, and no problems were reported. However, emissions from only two of four parallel stacks were measured.

4.2.1.26 Reference 29. This report documents measurements of SO_2, NO_x, CO, and controlled filterable, organic, and PM inorganic emissions from a coal-fired rotary kiln with preheater. The test was conducted in June 1974 and was sponsored by EPA to provide information to be used for developing an NSPS for lime manufacturing. The exhaust gas from the kiln first passes through a multiclone, then is cooled with a combination of water spray and tempering air, and then is ducted to a fabric filter. The fabric filter has 12 compartments and six stacks. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate. Operation of the kiln and fabric filter was reported to be normal during the testing.

Particulate matter emissions were measured generally in accordance with Method 5. Two variations to the standard protocol were reported. One hundred milliliters (ml) of water were added to the third impinger, and the testing crew used a stationary impinger box connected to the heated filter box with teflon tubing. Neither variation was considered to introduce significant error in the data. One PM run was conducted on each of the six stacks. The back half of the Method 5 sampling train was analyzed for condensible inorganic PM and condensible organic PM. The data tables in the report indicate that an organic extract was used to quantify the organic fraction, but no other details are provided.

Sulfur dioxide testing was conducted in accordance with Method 6. One SO_2 run was conducted on each of the six stacks. The tests were not run for the complete 4-hour period due to carry-over of the sulfuric acid fraction in the isopropanol impinger. No other problems were reported with the SO_2 sampling. Testing for NO_x was conducted in accordance with EPA Method 7. Four samples were collected during each of three PM runs. No difficulties with the NO_x testing were reported. Testing for CO was conducted generally in accordance with EPA Method 10. One run was conducted during each of three PM runs. Integrated bag samples were collected during the PM testing, but difficulties were encountered during the testing while passing the sample through the ascarite. This difficulty caused a flow restriction in the inlet tube to the ascarite container. The report does not discuss the effect this problem could have had on the results. However, the data showed a wide range in CO concentrations (15 to 580 ppm). Emission factors for CO_2 were developed using data from the Orsat analysis. These data were generated during the PM testing.

Emission factors were developed for filterable PM, condensible inorganic PM, condensible organic PM, SO_2, NO_x, and CO_2 emissions. The emission data for CO are rated D because of the sampling difficulties and the wide range in the data. All other emission data are rated C. The PM, SO_2, and CO_2 data constitute a single run on the entire fabric filter. In addition, details on the back-half analysis of the PM sampling train are not provided. The NO_x data constitute a single run on three of the six fabric filter stacks.

4.2.1.27 Reference 30. This report documents measurements of uncontrolled and controlled filterable PM emissions from a rotary lime kiln. The kiln was fired by 50 percent coal and 50 percent natural gas. The test was conducted in May 1974 to evaluate the efficiency of the horizontal venturi scrubber on the lime kiln. Process rates are provided on the basis of lime production.

The PM sampling and analytical methods are not specified in the report. Three test runs were conducted upstream and downstream of the scrubber. Data for the first test run were discounted because the isokinetic flow rate was unacceptable. Concentrations of CO_2 in the exhaust stream were measured using Orsat, but only a single reading is reported.

Emission factors were developed for uncontrolled and controlled filterable PM emissions and for CO_2 emissions. The PM data are rated D because the test and analytical methods were not specified, and the report generally was lacking in other details. The CO_2 data are unrated because only a single measurement was recorded.

4.2.1.28 Reference 31. This report documents measurements of controlled filterable and condensible inorganic PM emissions from a rotary lime kiln. Particulate emissions from the kiln were controlled by a venturi scrubber. The test was conducted on September 23, 1975 as a compliance test. The fuel for the kiln was not reported. Process rates were provided on the basis of feed; production rates were estimated as half of the feed rate.

Three test runs were conducted on the outlet to the venturi scrubber. The tests were conducted in accordance with EPA Method 5, but it is unclear from the report which portion of the sample catch represented filterable PM and which portion represented condensible inorganic PM. In addition, the report does not describe the method of sample analysis.

Emission factors were developed for controlled filterable and condensible inorganic PM emissions. The emission data are rated D because of the lack of adequate documentation in the report.

4.2.1.29 Reference 50. This report documents measurements of emissions of filterable PM from six raw material processing sources and measurements of emissions of filterable PM, SO_2, NO_x, and CO from a parallel flow regenerative lime kiln that was fueled with natural gas. The raw material processing sources tested included the following stages of the process: primary crushing, including the scalping screen, scalping screen discharges, primary crusher, primary crusher discharges, and ore discharge; primary screening, including the screen feed, screen discharge, and surge bin discharge; two conveyor transfer points on the conveyor from the primary crusher to the primary stockpile; secondary and tertiary screening (two points), including the conveyor transfer point for the primary stockpile underflow to the secondary screen, secondary screen, tertiary screen, and tertiary screen discharge.

Fabric filters are used to control emissions from each of the sources tested, and only controlled emissions were tested. The test was conducted in February 1993 to demonstrate compliance with State regulations. Process rates were provided on the basis of feed rate for the raw material processing sources and lime production rate for the kiln.

Filterable PM emissions were quantified using Method 5; SO_2 emissions were quantified using Method 6C; NO_x emissions were quantified using Method 7E; and CO emissions were quantified with Method 10. In all cases, three test runs were conducted.

Emission factors for filterable PM were developed from all seven sources. The emission factors for the conveyor transfer points were combined to yield an average filterable PM emission factor because both sources were located on the same conveyor. In addition, the emission factors for both secondary/tertiary screening sources were combined because both emission points included a combination of sources associated with both secondary and tertiary screening, and the report did not provide adequate information for isolating secondary from tertiary screening. Table 4-3 includes only the combined data for these four sources.

Emission factors also were developed for emissions of filterable PM, SO_2, NO_x, and CO from the parallel flow regenerative kiln. All of the emission factors developed from this reference are rated A.

4.2.2 Estimate of Theoretical CO_2 Emission Factors for Lime Kilns

Carbon dioxide is emitted from lime manufacturing kilns by two mechanisms: the reduction of carbonate (CO_3^{-2}) in the limestone feed material to CO_2 and the oxidation of carbon in the fuel to CO_2. Assuming complete reduction of CO_3^{-2}, the emission factor for the first reaction in units of kg of CO_2 per

Mg of lime produced is estimated to be 920 kg/Mg (1,830 lb/ton) for dolomitic lime and 785 kg/Mg (1,570 lb/ton) for high-calcium lime.

The CO_2 emission factor for the second reaction is a function of the carbon content of the fuel and the fuel consumption rate. Based on the test reports reviewed for this report, the consumption rate for coal, the most commonly used fuel in lime kilns, ranged from 0.18 to 0.35 and averaged 0.27 Mg coal per Mg of lime produced. The carbon content of bituminous coal ranges from 75.5 percent to 90.5 percent by weight; the midpoint of this range is 83 percent. Assuming complete oxidation of C to CO_2, the emission factor for the second reaction ranges from 498 kg/Mg (997 lb/ton), for 75.5 percent carbon coal utilized at a fuel consumption rate of 0.18 Mg/Mg, to 1,160 kg/Mg (2,320 lb/ton) for 90.5 percent carbon coal utilized at a consumption rate of 0.35 Mg/Mg. Using the average coal consumption rate of 0.27 Mg/Mg and an average carbon content of 83 percent, the average emission factor due to combustion is estimated as 820 kg/Mg (1,640 lb/ton).

Combining the CO_2 emission factors for the two reactions yields average CO_2 emission factors of 1,750 kg/Mg (3,500 lb/ton) for dolomitic lime and 1,600 kg/Mg (3,200 lb/ton) for high-calcium lime. As these results indicate, the first of these two reactions accounts for approximately 70 to 85 percent of the CO_2 emissions from lime kilns, depending on the carbon content of the fuel, the fuel consumption rate, and the type of lime produced. The calculations and data that form the basis for these CO_2 emission factor estimates are provided in Appendix A.

4.2.3 Review of XATEF and SPECIATE Data Base Emission Factors

The XATEF data base did not include any emission factors for the lime manufacturing industry. The SPECIATE data base includes emission factors for a number of speciated inorganic and volatile compounds (VOC's) from limestone loading, crushing, screening, conveying, calcining, cooling, hydrating, and storing. However, the emission factors are all surrogates, which are based on averages for the mineral products industry as a whole.

4.2.4 Review of Test Data in AP-42 Background File

As stated in Section 4.2 of this report, the majority of documents used to prepare this revision to AP-42 were found in the background file for the section; only five new test reports (References 23 to 26 and Reference 50) were reviewed. All of the references were described previously in Section 4.2.1 of this report.

The previous version of AP-42 includes emission factors for controlled calcimatic kilns and for uncontrolled vertical kilns. However, data on emissions from these sources could not be located in the background file. Apparently, the data on which these emission factors were based were found in Reference 5 of the previous version of the section. This reference is identified in the list of references as "Source test data on lime plants, Office of Air Quality Planning and Standards." Because there was no way to corroborate the data, these emission factors from the previous version of Section 11.15 were not retained in the revised section.

4.2.5 Results of Data Analysis

This section discusses the analysis of the data and describes how the data were used to develop average emission factors for lime manufacturing. These average emission factors are listed in Table 4-5. As described in Section 4.2, emission factors for kilns, coolers, and hydrators are presented in units of mass of pollutant emitted per mass of lime produced. Emission factors for mechanical processing, such as screening, grinding, and materials transfer, are presented in units of mass of pollutant emitted per mass of material processed. The following paragraphs describe how the emission data from individual test reports were used to develop the average emission factors for lime manufacturing. Emission factors for rotary kiln emissions are discussed first, followed by emission factors for calcimatic kilns, parallel flow regenerative kilns, hydrators, product coolers, and other material processing sources.

The emission factor ratings assigned to each of the average emission factors developed for lime manufacturing are based on the emission data ratings and the number of tests conducted. Of the 145 data sets from which emission factors were developed, 19 were A-rated, 34 were B-rated, 62 were C-rated, and 30 were D-rated. In general, A- and B-rated data are not supposed to be averaged with C- and D-rated data. However, emission factors based on C-rated data were averaged with A- and B-rated data if the number of C-rated tests were relatively large in comparison to the A- and B-rated tests and the data were consistent between A-, B-, and C-rated tests. D-rated data were used only when no A- or B-rated data were available.

4.2.5.1 Coal-Fired Rotary Kilns.

Filterable PM. Emission factors for uncontrolled filterable PM emissions from coal-fired rotary kilns were developed from two A-rated tests. The results of these two tests, 170 and 190 kg/Mg (330 and 370 lb/ton), were averaged to produce an average emission factor of 180 kg/Mg (350 lb/ton) for uncontrolled filterable PM emissions. This emission factor is rated D.

Emission factors for filterable PM emissions from large-diameter cyclone-controlled rotary kilns are available for one A-rated test and one C-rated emission test. A-rated data generally are not averaged with C-rated data. In addition, the A-rated test consisted of 15 runs, whereas the C-rated test consisted of only 2 test runs. Therefore, the C-rated data were discarded, and only the A-rated data were used to develop the emission factor for filterable PM emissions controlled with a large-diameter cyclone. This emission factor is rated D.

Emission factors for filterable PM emissions from fabric filter-controlled rotary kilns are available for one A-rated test, one B-rated emission test, two C-rated tests, and four D-rated tests. The emission factors developed from D-rated data averaged 0.61 kg/Mg (1.2 lb/ton), and the emission factors developed from the remaining data averaged 0.14 kg/Mg (0.28 lb/ton). The D-rated data were discarded, and the A-, B-, and C-rated data were used to develop the average emission factor for filterable PM emissions with fabric filter control. This emission factor is based on a total of five tests and is rated D.

For filterable PM emissions from ESP-controlled rotary kilns, data were available only from a single A-rated test. This emission factor is rated D.

Emission factors for filterable PM emissions from venturi scrubber-controlled rotary kilns were developed from three B-rated emission tests, two C-rated tests, and one D-rated test. The emission factors developed from B-rated data average 0.72 kg/Mg (1.4 lb/ton), and the emission factors developed from C-rated data average 3.1 kg/Mg (6.1 lb/ton). Only the B-rated data were used to determine the average emission factor for filterable PM emissions from venturi scrubber controlled rotary kilns. This emission factor is based on three emission tests and is rated D.

Filterable PM-10. Particle size distribution data were available for uncontrolled rotary kilns, ESP-controlled rotary kilns, and fabric filter-controlled rotary kilns. The size distributions are summarized in Table 4-4. Emission factors for PM-10 emissions from coal-fired rotary kilns were developed by multiplying the cumulative percent below 10μ by the average filterable PM emission factors developed for coal-fired rotary kilns. The PM-10 emission factors are rated D. These emission factors were developed from a combination of A- and C-rated particle size data and D-rated filterable PM emission factors.

Condensible inorganic PM. For condensible inorganic PM emissions from rotary kilns, data from two emission tests were available: one test on an uncontrolled kiln, and one test on a large-diameter cyclone-controlled kiln. The data from both tests were rated C. Because cyclones are expected to have negligible effects on condensible inorganic PM emissions, emission factors developed from the two tests were averaged. The resulting average emission factor is rated E.

Emission factors for condensible inorganic PM emissions from fabric filter-controlled rotary kilns were developed from two C-rated tests and four D-rated tests. The emission factor developed from C-rated data averaged 0.13 kg/Mg (0.25 lb/ton), and the emission factor from D-rated data averaged 0.22 kg/Mg (0.45 lb/ton). The average emission factor for condensible inorganic PM emissions from fabric filter-controlled rotary kilns was determined by averaging the results from all six tests. This emission factor is rated E.

Emission factors for condensible inorganic PM emissions from venturi scrubber-controlled rotary kilns were developed from one B-rated emission test, two C-rated tests, and one D-rated test. The B-rated test (0.12 kg/Mg [0.24 lb/ton]) and one of the C-rated tests (0.33 kg/Mg [0.65 lb/ton]) were conducted on the same rotary kiln, and the results from these two tests were first averaged to determine an average emission factor from that specific kiln. This emission factor was then averaged with the emission factor from the other C-rated test in order to determine the average emission factor

TABLE 4-5. SUMMARY OF AVERAGE EMISSION FACTORS FOR LIME MANUFACTURING[a]

Source	Type of control	Pollutant	No. of tests	Emission factor, kg/Mg	Emission factor, lb/ton	Rating	References
Rotary kiln (coal-fired)	None	Filterable PM	2	180	350	D	6, 7
Rotary kiln (coal-fired)	None	Filterable PM-10	b	22	42	D	1, 6, 7
Rotary kiln (coal-fired)	Large diam. cyclone	Filterable PM	1	60	120	D	7
Rotary kiln (coal-fired)	Fabric filter	Filterable PM	4	0.14	0.28	D	7, 15, 26, 28
Rotary kiln (coal-fired)	Fabric filter	Filterable PM-10	b	0.077	0.15	D	1, 7, 15, 26, 28
Rotary kiln (coal-fired)	ESP	Filterable PM	1	4.3	8.5	D	7
Rotary kiln (coal-fired)	ESP	Filterable PM-10	b	2.2	4.3	D	1, 7
Rotary kiln (coal-fired)	Venturi scrubber	Filterable PM	3	0.72	1.4	D	5, 23, 24
Rotary kiln (coal-fired)	None	Condensible inorganic PM	2	0.67	1.3	E	6,8
Rotary kiln (coal-fired)	Fabric filter	Condensible inorganic PM	6	0.19	0.38	E	3, 15, 16, 17, 18, 28
Rotary kiln (coal-fired)	Venturi scrubber	Condensible inorganic PM	3	0.14	0.28	D	5, 10, 11
Rotary kiln (coal-fired)	None	Condensible organic PM	1	0.51	1.0	E	6
Rotary kiln (coal-fired)	None	SO_2	2	2.7	5.4	D	6, 15
Rotary kiln (coal-fired)	Fabric filter	SO_2	3	0.83	0.17	D	15, 26, 28
Rotary kiln (coal-fired)	Wet scrubber	SO_2	2	0.15	0.3	D	22
Rotary kiln (coal-fired)	None	NO_x	5	1.6	3.1	C	6, 8, 15, 26, 28
Rotary kiln (coal-fired)	None	CO	3	0.74	1.5	D	15, 22
Rotary kiln (coal-fired)	None	CO_2	9	1,600	3,200	C	5, 6, 21, 22, 23, 24, 26
Rotary kiln (coal-fired)	Venturi scrubber	SO_3	1	0.11	0.21	E	10
Rotary kiln (gas-fired)	ESP	Filterable PM	1	0.086	0.17	E	9
Rotary kiln (gas-fired)	Gravel bed	Filterable PM	2	0.51	0.99	E	12, 27
Rotary kiln (gas-fired)	ESP	Condensible inorganic PM	1	0.11	0.22	E	9
Rotary kiln (gas-fired)	Gravel bed filter	Condensible inorganic PM	1	0.24	0.48	E	12, 27
Rotary kiln (gas-fired)	None	NO_x	1	1.7	3.5	E	9
Rotary kiln (gas-fired)	None	CO	1	1.1	2.2	E	9
Rotary kiln (coal/gas-fired)	None	Filterable PM	1	40	80	E	14

TABLE 4-5. (continued)

Source	Type of control	Pollutant	No. of tests	Emission factor, kg/Mg	Emission factor, lb/ton	Rating	References
Rotary kiln (coal/gas-fired)	Venturi scrubber	Filterable PM	1	0.44	0.87	D	14
Rotary kiln (coal/gas-fired)	Venturi scrubber	Condensible inorganic PM	1	0.041	0.082	D	14
Rotary kiln (coal/gas-fired)	Venturi scrubber	NO_x	1	1.4	2.7	D	14
Rotary kiln (coal/gas-fired)	Venturi scrubber	CO	1	0.41	0.83	D	14
Rotary kiln (coal/gas-fired)	Venturi scrubber	CO_2	1	1,600	3,200	D	14
Rotary kiln (coal/coke-fired)	Venturi scrubber	Filterable PM	1	0.83	1.7	D	25
Rotary kiln (coal/coke-fired)	Venturi scrubber	CO_2	1	1,500	3,000	D	25
Rotary preheater kiln (coal-fired)	Multiclone	Filterable PM	1	42	84	E	8
Rotary preheater kiln (coal-fired)	Gravel bed filter	Filterable PM	1	0.59	1.2	E	13
Rotary preheater kiln (coal-fired)	Multiclone/ water spray/ fabric filter	PM, filterable	1	0.56	1.1	E	29
Rotary preheater kiln (coal-fired)	Multiclone/ water spray/ fabric filter	PM, condensible inorganic	1	0.57	1.1	E	29
Rotary preheater kiln (coal-fired)	Multiclone/ water spray/ fabric filter	PM, condensible organic	1	0.076	0.15	E	29
Rotary preheater kiln (coal-fired)	Multiclone	Condensible inorganic PM	1	0.040	0.081	E	8
Rotary preheater kiln (coal-fired)	Dry PM controls	SO_2	2	1.1	2.3	E	13, 21
Rotary preheater kiln (coal-fired)	Multiclone/ water spray/ fabric filter	SO_2	1	3.2	6.4	E	29
Rotary preheater kiln (coal-fired)	None	CO	1	3.2	6.3	E	29
Rotary preheater kiln (coal-fired)	None	CO_2	3	1,200	2,400	D	21
Calcimatic kiln (gas-fired)	None	Filterable PM	1	48	97	E	20

TABLE 4-5. (continued)

Source	Type of control	Pollutant	No. of tests	Emission factor, kg/Mg	Emission factor, lb/ton	Rating	References
Calcimatic kiln (gas-fired)	None	Condensible inorganic PM	1	0.14	0.27	E	20
Calcimatic kiln (gas-fired)	None	NO_x	1	0.076	0.15	D	20
Calcimatic kiln (gas-fired)	None	CO_2	1	1,300	2,700	E	20
Parallel flow regenerative kiln (gas-fired)	Fabric filter	PM, filterable	1	0.026	0.051	D	50
Parallel flow regenerative kiln (gas-fired)	Fabric filter	SO_2	1	0.00060	0.0012	D	50
Parallel flow regenerative kiln (gas-fired)	None	NO_x	1	0.12	0.24	D	50
Parallel flow regenerative kiln (gas-fired)	None	CO	1	0.23	0.45	D	50
Atmospheric hydrator	Wet scrubber	Filterable PM	1	0.033	0.067	D	19
Atmospheric hydrator	Wet scrubber	Condensible inorganic PM	1	0.0067	0.013	D	19
Cooler	None	Filterable PM	1	3.4	6.8	E	20
Cooler	None	Condensible inorganic PM	1	0.011	0.023	E	20
Cooler	None	CO_2	1	3.9	7.8	E	20
Primary crushing[c]	None	Filterable PM	1	0.0083	0.017	E	2
Scalping screen and hammermill[c]	None	Filterable PM	1	0.31	0.62	E	2
Primary crushing[d]	Fabric filter	PM, filterable	1	0.00021	0.00043	D	50
Primary screening[e]	Fabric filter	PM, filterable	1	0.00030	0.00061	D	50
Crushed material conveyor transfer[f]	Fabric filter	PM, filterable	1	$4.4x10^{-5}$	$8.8x10^{-5}$	D	50
Secondary and tertiary screening[g]	Fabric filter	PM, filterable	1	$6.5x10^{-5}$	0.00013	D	50
Product transfer and conveying[c]	None	Filterable PM	1	1.1	2.2	E	7
Product loading (enclosed truck)[c]	None	Filterable PM	1	0.31	0.61	D	7
Product loading (open truck)[c]	None	Filterable PM	1	0.75	1.5	D	7

[a]Emission factors in units of kg/Mg (lb/ton) of lime produced except where indicated.

TABLE 4-5. (continued)

[b]Based on average particle size distribution presented in Table 4-4.

[c]Emission factors in units of kg/Mg (lb/ton) of stone or product processed.

[d]Emission factors in units of kg/Mg (lb/ton) of material processed. Includes scalping screen, scalping screen discharges, primary crusher, primary crusher discharges, and ore discharge.

[e]Emission factors in units of kg/Mg (lb/ton) of material processed. Includes primary screening, including the screen feed, screen discharge, and surge bin discharge.

[f]Emission factors in units of kg/Mg (lb/ton) of material processed. Based on average of three runs each of emissions from two conveyor transfer points on the conveyor from the primary crusher to the primary stockpile.

[g]Emission factors in units of kg/Mg (lb/ton) of material processed. Based on sum of emissions from two emission points that include conveyor transfer point for the primary stockpile underflow to the secondary screen, secondary screen, tertiary screen, and tertiary screen discharge.

for condensible inorganic PM emissions from venturi scrubber-controlled rotary kilns. This emission factor is rated D.

Condensible organic PM. For condensible organic PM emissions from rotary kilns, data from one emission test were available on an uncontrolled kiln. The test is rated C, and an E-rated emission factor was developed from the data set for AP-42 Section 11.15.

Filterable and condensible inorganic PM. Reference 5 documents a Method 5 emission test for which the filter was placed after the impingers. Because of this modification to the sampling train, only combined uncontrolled filterable and condensible inorganic PM were reported. Because separate filterable PM and condensible inorganic PM data were presented in several other test reports reviewed, the emission factor developed from these C-rated data were not incorporated in AP-42 Section 11.15. It should be noted that the emission factor developed from these Reference 5 data is approximately 33 percent less than the uncontrolled filterable PM emission factor developed from other test data.

Sulfur dioxide. For SO_2 emissions from coal-fired rotary kilns, emission factors were developed from 13 tests. Three tests (rated A, B, and D) were conducted on uncontrolled kilns; two tests (both rated C) were conducted on kilns with only settling chambers as controls; four tests (two B-rated, one C-rated, and one D-rated) were conducted on fabric filter-controlled kilns; and four tests (two B-rated, one C-rated, and one D-rated) were conducted on kilns controlled with wet scrubbers.

Because settling chambers were assumed to have negligible effects on SO_2 emissions, the test results from the settling chamber-controlled kilns were treated as uncontrolled emissions. The data from both of these tests (5.8 and 5.9 kg/Mg [12 and 12 lb/ton]) were rated C. Because A- and B-rated data were available, the C-rated data were not used in determining an average emission factor for uncontrolled SO_2 emissions from rotary kilns. The D-rated data also were discarded. The average emission factor developed from the A- and B-rated data is rated D.

Emission factors for SO_2 emissions from fabric filter-controlled rotary kilns were developed from two B-rated tests, one C-rated test, and one D-rated test. Fabric filters generally achieve only incidental control of SO_2 emissions. However, the data indicate a significant difference between uncontrolled and fabric filter-controlled SO_2 emissions. Therefore, a separate average emission factor was developed for fabric filter-controlled SO_2 emissions. The emission factors developed from the B-rated tests averaged 1.2 kg/Mg (2.3 lb/ton), the emission factor developed from the C-rated test was 0.18 kg/Mg (0.37 lb/ton), and the emission factor from the D-rated test was calculated as 5.3 kg/Mg (11 lb/ton). The B-rated and C-rated test data were combined to develop an average emission factor for SO_2 emissions from fabric filter-controlled rotary kilns. This emission factor is rated D.

Emission factors for SO_2 emissions from wet scrubber-controlled rotary kilns were developed from two B-rated tests, one C-rated test, and one D-rated test. The C-rated and one of the B-rated tests were conducted on the same kiln. However, the B-rated test was conducted one year later than the C-rated test, and the B-rated data are an order of magnitude lower than the C-rated data. It is unknown if the difference in the results of the two tests was due to a process change. Therefore, the B- and C-rated data for this kiln were not combined. The D-rated and the other B-rated test also were conducted on the same kiln. Only the B-rated test data were used to develop an average emission factor for SO_2 emissions from wet scrubber-controlled rotary kilns.

Nitrogen oxides. For NO_x emissions from coal-fired rotary kilns, emission factors were developed from five emission tests. Two tests (both rated A) were conducted on uncontrolled kilns, and three tests (two rated B and one rated C) were conducted on fabric filter-controlled kilns. Because fabric filters have a negligible effect on NO_x emissions, all five tests were treated as uncontrolled emission measurements. The emission factors from both the combined A- and B-rated data and the C-rated data averaged 1.6 kg/Mg (3.0 lb/ton). Because the five tests showed consistent results, the data from all five tests were used to develop an average emission factor for NO_x emissions from coal-fired rotary kilns. Because this emission factor is based on five emission tests and the data are relatively consistent, the NO_x emission factor is rated C.

Carbon monoxide. For CO emissions from coal-fired rotary kilns, emission factors were developed from five emission tests. One test was conducted on an uncontrolled kiln, two tests were conducted on settling chamber-controlled kilns, and two tests were conducted on fabric filter-controlled kilns. Fabric filters and settling chambers generally have negligible effects on CO emissions. Therefore, the results from the five tests were treated as measurements of uncontrolled emissions.

One of the tests was rated B, two of the tests were rated C, and two of the tests were rated D. The D-rated data were discarded. The emission factors developed from the C-rated data ranged from 0.45 to 1.4 kg/Mg (0.90 to 2.7 lb/ton). The emission factor developed from the B-rated test was determined to be 0.38 kg/Mg (0.76 lb//ton). Because there was only a single B-rated test and two C-rated tests, the results from all three B- and C-rated tests were combined to develop an average emission factor for CO emissions from coal-fired rotary kilns. The average emission factor was determined to be 0.74 kg/Mg (1.5 lb/ton). This emission factor is rated D.

Carbon dioxide. For CO_2 emissions from coal-fired rotary kilns, emission factors were developed from 17 emission tests. Three tests were conducted on uncontrolled kilns, 5 tests were conducted on kilns controlled with wet scrubbers, and the other 9 tests were conducted on kilns with PM controls (settling chambers or fabric filters), which are expected to have negligible effects on CO_2 emissions. Although wet scrubbers generally achieve some level of CO_2 control, the emission factors developed from the wet scrubber-controlled kilns do not indicate a reduction in emissions over the uncontrolled tests. Therefore, the results of all 17 tests were treated as measurements of uncontrolled CO_2 emissions.

Of the 17 CO_2 emission tests, 1 of the tests was rated A, 8 of the tests were rated B, 6 of the tests were rated C, and 2 of the tests were rated D. Because of the relatively large number of A- and B-rated tests, the C- and D-rated data were discarded. The emission factors developed from the A- and B-rated tests ranged from 940 to 2,500 kg/Mg (1,900 to 4,900 lb/ton) and averaged 1,600 kg/Mg (3,200 lb/ton). This emission factor is rated C. In comparison to the theoretical average emission factor for CO_2 emissions (1,100 kg/Mg [2,200 lb/ton]) discussed in Section 4.2.2, the magnitude of this average emission factor appears to be reasonable.

Sulfur trioxide. One of the test reports reviewed included C-rated data on SO_3 emissions from a venturi scrubber-controlled rotary kiln. The emission factor for SO_3 emissions from coal-fired rotary kilns developed from this report is rated E.

4.2.5.2 Gas-Fired Rotary Kilns.

Filterable PM. Emission factors for filterable PM emissions from gas-fired rotary kilns were developed from three emission tests. One of the tests was conducted on an ESP-controlled rotary kiln. The data from this test were rated C, and an E-rated emission factor was developed from the data. The other two tests were conducted on rotary kilns controlled with gravel bed filters. The data from one of these tests were rated C and the data from the other test were rated D. The results of these two tests, 0.44 and 0.57 kg/Mg (0.87 and 1.1 lb/ton), were combined to develop an average emission factor for filterable PM emissions from a gravel bed filter-controlled gas-fired rotary kiln. This emission factor also is rated E.

Condensible inorganic PM. Emission factors for condensible inorganic PM emissions from gas-fired rotary kilns also were developed for one ESP-controlled rotary kiln and for two rotary kilns controlled with gravel bed filters. The data from the ESP-controlled kiln test were rated C, and an E-rated emission factor was developed from the data. The data from the gravel bed filter-controlled kiln tests were rated D. The results of these two tests, 0.022 and 0.46 kg/Mg (0.045 and 0.91 lb/ton), were combined to develop an average emission factor for condensible inorganic PM emissions from a gravel bed filter-controlled gas-fired rotary kiln. This emission factor also is rated E.

Nitrogen oxides. For NO_x emissions from gas-fired rotary kilns, an emission factor was developed from a single C-rated test conducted on an ESP-controlled kiln. Because ESP's have negligible effects on NO_x emissions, the data were treated as measurements of uncontrolled emissions. The emission factor developed from this test is rated E.

Carbon monoxide. For CO emissions from gas-fired rotary kilns, an emission factor was developed from a single C-rated test conducted on an ESP-controlled kiln. Because ESP's have negligible effects on CO emissions, the data were treated as measurements of uncontrolled emissions. The emission factor developed from this test is rated E.

4.2.5.3 Coal- and Gas-Fired Rotary Kilns. Two of the test reports reviewed documented tests on rotary kilns that were fired with a combination of gas and coal. Reference 14 documents measurements of emissions from a kiln that was fired with 60 percent coal and 40 percent gas (heat value basis), and Reference 30 documents emission measurements for a kiln fired with 50 percent coal and 50 percent gas. The emission factors developed from these tests are discussed in the following paragraphs.

Filterable PM. Data were available on one D-rated test of uncontrolled filterable PM emissions from a coal- and gas-fired rotary kiln. The emission factor developed from these data is rated E. For venturi scrubber-controlled emissions from coal- and gas-fired rotary kilns, two tests were reviewed. The data from one of the tests were rated B, and the data from the second test were rated D. The D-rated data were discarded, and a D-rated emission factor was developed from the B-rated test.

Condensible inorganic PM. For condensible inorganic PM emissions from coal- and gas-fired rotary kilns, an emission factor was developed from a single B-rated test conducted on a venturi scrubber-controlled kiln. This emission factor is rated D.

Nitrogen oxides. For NO_x emissions from coal- and gas-fired rotary kilns, an emission factor was developed from a single B-rated test conducted on a venturi scrubber-controlled kiln. The emission factor developed from this test is rated D.

Carbon monoxide. For CO emissions from coal- and gas-fired rotary kilns, an emission factor was developed from a single B-rated test conducted on a venturi scrubber-controlled kiln. The emission factor developed from this test is rated D.

Carbon dioxide. Data were available on one D-rated test and one B-rated test of CO_2 emissions from coal- and gas-fired rotary kilns. The D-rated data were discarded. The B-rated test was conducted on a venturi scrubber-controlled kiln. The emission factor developed from this test is rated D. In comparison to the theoretical average emission factor for CO_2 emissions (1,100 kg/Mg [2,200 lb/ton]) discussed in Section 4.2.2, the magnitude of this average emission factor appears to be reasonable.

4.2.5.4 Coal- and Coke-Fired Rotary Kilns. One of the test reports reviewed (Reference 25) documented tests on a rotary kiln that was fired with a combination of coke (70 percent) and coal (30 percent). The report includes B-rated data on filterable PM and CO_2 emissions from a kiln controlled with a venturi scrubber. D-rated emission factors were developed for emissions of each of these pollutants from kilns fired with a combination of coke and coal.

4.2.5.5 Coal-Fired Rotary Kilns with Preheaters. Four of the test reports reviewed documented tests on coal-fired rotary kilns equipped with preheaters. Reference 8 includes data on filterable and condensible PM, NO_x, and CO_2 emissions; Reference 13 includes data on filterable PM, SO_2, and CO_2 emissions; Reference 21 documents emissions of SO_2 and CO_2; and Reference 29 documents emissions of filterable PM, condensible inorganic PM, condensible organic PM, SO_2, NO_x, CO, and CO_2.

Particulate matter. Emission factors for multiclone-controlled filterable PM emissions, gravel bed filter-controlled filterable PM emissions, and multiclone-controlled condensible inorganic PM emissions were each developed from single C-rated tests. In addition, emission factors for filterable PM, condensible organic PM, and condensible inorganic PM from rotary preheater kilns controlled with a combination of multiclone, water spray, and fabric filter were developed from C-rated data. These emission factors are rated E.

Sulfur dioxide. Three of the reports documented emissions of SO_2 from rotary preheater kilns. In one test, emissions were controlled with a gravel bed filter, and in another test, emissions were controlled with a fabric filter. Both of these types of control devices are expected to have a minor but similar effect on SO_2 emissions. Therefore, the data were treated as SO_2 emissions from kilns controlled with generic dry PM control devices. Both sets of data were rated C, and emission factors developed from both (0.33 and 1.9 kg/Mg [0.65 and 3.9 lb/ton]) were combined for an average emission factor of 1.1 kg/Mg (2.3 lb/ton). In the third test, emissions were controlled with a combination of multiclone, water spray, and fabric filter. The data from this C-rated test was used to develop an E-rated emission factor.

Nitrogen oxides. For NO_x emissions from coal-fired rotary preheater kilns, an emission factor was developed from a single A-rated test conducted on an uncontrolled kiln. The emission factor developed from this test is rated D. Data also were available from a C-rated test on a rotary preheater kiln controlled with a combination multiclone, water spray, and fabric filter. Although these controls are expected to have a negligible effect on NO_x emissions, these data were not combined with the A-rated data because of their C rating.

Carbon monoxide. Data were available for CO emissions from one test on a rotary preheater kiln. Kiln emissions were controlled with a combination multiclone, water spray, and fabric filter, which are expected to have negligible effects on CO emissions. The data were rated D and were used to develop an E-rated emission factor for uncontrolled CO emissions.

Carbon dioxide. Data were available for three B-rated tests and three C-rated tests of CO_2 emissions from coal-fired rotary preheater kilns. One of the kilns was uncontrolled and for the other five tests kiln emissions were controlled with gravel bed filters, settling chambers, or fabric filters. Because these control devices generally have negligible effects on CO_2 emissions, the data were treated as measurements of uncontrolled emissions. The emission factors developed from the C-rated data averaged 1,900 kg/Mg (3,800 lb/ton), and the B-rated data averaged 1,200 kg/Mg (2,400 lb/ton). The C-rated data were discarded, and the B-rated data were used to develop an average emission factor for CO_2 emissions from rotary preheater kilns. This emission factor is rated D. In comparison to the theoretical average emission factor for CO_2 emissions (1,100 kg/Mg [2,200 lb/ton]) discussed in Section 4.2.2, the magnitude of this average emission factor appears to be reasonable.

4.2.5.6 Gas-Fired Calcimatic Kilns. One of the test reports reviewed (Reference 20) documented emissions from two gas-fired calcimatic lime kilns. Emission factors were developed for uncontrolled filterable PM, condensible inorganic PM, NO_x, and CO_2 emissions. The NO_x data were rated A and were used to develop a D-rated emission factor for NO_x emissions from gas-fired calcimatic kilns. All other data from Reference 20 were rated C or D and were used to develop E-rated emission factors for gas-fired calcimatic kilns.

4.2.5.7 Gas-Fired Parallel Flow Regenerative Kilns. One of the test reports reviewed (Reference 50) documented emissions from a gas-fired parallel flow regenerative kiln. Emission factors were developed for emissions of filterable PM, SO_2, NO_x, and CO. The data were rated A, and the emission factors developed from the data are rated D.

4.2.5.8 Atmospheric Hydrators. Two of the test reports reviewed documented filterable and condensible inorganic PM emissions from atmospheric lime hydrators controlled with wet scrubbers. Reference 15 includes C-rated data, and Reference 19 includes B-rated data. The C-rated data were discarded, and D-rated emission factors were developed from the B-rated data for filterable PM and condensible inorganic PM emissions from lime hydrators.

4.2.5.9 Product Coolers. One of the test reports reviewed documented emissions of uncontrolled filterable PM, condensible inorganic PM, and CO_2 emissions from product coolers. All three data sets were rated C and were used to develop E-rated emission factors for cooler emissions.

4.2.5.10 Raw Material and Finishing Product Processing and Handling. Three of the documents reviewed documented PM emissions from various raw material and finished product processing and handling operations. Reference 2 includes C- and D-rated data on emissions from single sources (primary crushers and final sizing screens) and combinations of sources (primary crushers, scalping screens, and hammermills). The emissions from the final sizing screens and the combination primary crusher, scalping screens, and hammermill were controlled with fabric filters. Although condensible PM emissions were quantified, these data were disqualified because condensible emissions from these sources are considered negligible. Reference 50 includes A-rated data on fabric filter-controlled emissions from primary crushing, primary screening, crushed material conveyor transfer, and secondary and tertiary screening. Because the data from Reference 50 are of much higher quality, the controlled emission data from Reference 2 were discarded, and the following emission factors were developed for AP-42 Section 11.15: uncontrolled filterable PM for primary crushing; uncontrolled filterable PM for scalping screen and hammermill; and fabric filter-controlled filterable PM for primary crushing, primary screening, crushed material conveyor transfer, and secondary and tertiary screening. The uncontrolled emission factors are rated E and the controlled emission factors are rated D.

Reference 7 includes data on filterable PM emissions from material transfer and truck loading operations. The material transfer data were rated C and were used to develop an E-rated emission factor. The truck loading emission data include measurements of filterable PM emissions from enclosed trucks

(A-rated data) and from open trucks (B-rated data). These data were used to develop D-rated emission factors.

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5. AP-42 SECTION 11.15

LIME MANUFACTURING

A proposed revision of the existing AP-42 Section 8.15, Lime Manufacturing, is presented in the following pages as it would appear in the document.

APPENDIX A

ESTIMATE OF CARBON DIOXIDE EMISSION FACTOR FOR LIME KILNS

Carbon dioxide (CO_2) is emitted from lime manufacturing kilns by two mechanisms: the reduction of carbonate (CO_3^{-2}) in the limestone feed material to CO_2 and the oxidation of carbon in the fuel to CO_2. In the production of dolomitic lime (CaO·MgO), CO_3^{-2} is reduced to CO_2 according to the following reaction:

$$CaCO_3{\cdot}MgCO_3 + \text{heat} \rightarrow 2CO_2 + CaO{\cdot}MgO$$

Therefore, for each mole of dolomitic lime produced, two moles of CO_2 are emitted from the process. The molecular weights of CO_2 and CaO·MgO are 44 and 96, respectively. Therefore, for every 96 mass units of dolomitic lime produced, 88 mass units of CO_2 are emitted. The emission factor for CO_2 emissions from this reaction can be estimated in units of pounds (lb) of CO_2 emitted per ton of dolomitic lime produced as:

$$(88 \text{ lb } CO_2/96 \text{ lb lime}) \times 2{,}000 \text{ lb lime/ton lime} = 1{,}830 \text{ lb } CO_2\text{/ton lime}$$

To produce high-calcium lime, CO_3^{-2} in the feed material is reduced to CO_2 by the following reaction:

$$CaCO_3 + \text{heat} \rightarrow CO_2 + CaO$$

Using the same procedure as described above for dolomitic lime, the emission factor for CO_2 emissions from high-calcium lime production can be estimated as:

$$(44 \text{ lb } CO_2/56 \text{ lb lime}) \times 2{,}000 \text{ lb lime/ton lime} = 1{,}570 \text{ lb } CO_2\text{/ton lime}$$

Carbon dioxide also is emitted as a result of combustion in the lime kiln. Theoretical emissions of CO_2 from this mechanism can be estimated from the carbon content of the fuel and the fuel consumption rate. The carbon content of bituminous coal, which is the fuel used most commonly in lime kilns, ranges from 75.5 percent to 90.5 percent.[1] The midpoint of this range is 83 percent. To estimate the coal consumption rate, data from 15 references were used. These data are summarized in Table A-1

Table A-1. SUMMARY OF LIME KILN COAL CONSUMPTION DATA

Type of kiln	Average production rate, ton/hr	Average coal feed rate, ton/hr	Coal consumption, ton/ton lime	Ref.
Rotary	500.0	130	0.26	2
	14.0	4.65	0.33	3
	24.1	4.38	0.18	4
	13.2	4.37	0.33	5
	30.4	8.50	0.28	6
	25.8	6.70	0.26	7
	12.2	3.67	0.30	8
	21.4	6.07	0.28	9
	24.4	6.05	0.25	10
Calcimatic	15.3	4.08	0.27	11
Rotary with preheater	28.7	5.31	0.19	12
Rotary	11.5	4.00	0.35	13
	30.0	5.25	0.18	14
	19.1	5.72	0.30	15
	103.0	27.6	0.27	16
		Minimum	0.18	
		Maximum	0.35	
		Average	0.27	
		Standard deviation	0.054	

. Based on these data, the average coal consumption rate is 540 lbs/ton of lime produced. The emission factor for CO_2 emissions from coal combustion can be estimated in units of lbs of CO_2 emitted per ton of dolomitic lime produced as:

540 lb coal/ton lime x 0.83 x 44 lb CO_2/12 lb coal = 1,640 lb CO_2/ton lime

The overall estimated emission factor for CO_2 emissions from lime kilns is the sum of the emission factors for each of the two mechanisms. For dolomitic lime the CO_2 emission factor is estimated as:

1,830 + 1,640 = 3,470 lbs/ton

For high-calcium lime, the CO_2 emission factor is estimated as:

1,570 + 1,640 = 3,210 lb/ton

Table A-2 present the ranges in CO_2 emission factors that can be estimated from the data. These emission factors are based on the assumptions that the carbon in the coal is completely oxidized to CO_2, and that the carbonate in the limestone feed is completely reduced to CO_2. However, it is unlikely that these two reactions will be complete. Therefore, these emission factors are likely to be biased high.

Table A-2. ESTIMATED CO_2 EMISSION FACTORS FOR COAL-FIRED LIME KILNS

Type of lime	Coal consumption rate, ton/ton	Carbon content of coal, percent	Emission factor					
			Due to stone		Due to coal		Total	
			kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
Dolomitic	0.18	75.5	915	1,830	498	997	1,420	2,830
		83	915	1,830	550	1,199	1,470	2,930
		90.5	915	1,830	595	1,190	1,510	3,020
	0.27	75.5	915	1,830	745	1,490	1,660	3,320
		83	915	1,830	820	1,640	1,740	3,470
		90.5	915	1,830	895	1,790	1,810	3,620
	0.35	75.5	915	1,830	970	1,940	1,890	3,770
		83	915	1,830	1,065	2,130	1,980	3,960
		90.5	915	1,830	1,160	2,320	2,080	4,150
High-calcium	0.18	75.5	785	1,570	498	997	1,290	2,570
		83	785	1,570	550	1,100	1,340	2,670
		90.5	785	1,570	595	1,190	1,380	2,760
	0.27	75.5	785	1,570	745	1,490	1,530	3,060
		83	785	1,570	820	1,640	1,610	3,210
		90.5	785	1,570	895	1,790	1,680	3,360
	0.35	75.5	785	1,570	970	1,940	1,760	3,510
		83	785	1,570	1,065	2,130	1,850	3,700
		90.5	785	1,570	1,160	2,320	1,950	3,890

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TABLE 4-1. SUMMARY OF EMISSION TEST REPORTS USED TO DEVELOP EMISSION FACTORS

Company name	Plant location	Sources tested	Pollutants	Year	Ref.
J. M. Brenner	Lancaster, PA	Primary crusher, screens, hammermill, final sizing screens	PM	1974	2
Marblehead Lime	Bellefonte, PA	Rotary kiln	PM	1975	3
J. E. Baker	Millersville, OH	Rotary kiln	PM, CO_2	1975	5
Virginia Lime	Ripplemead, VA	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1975	6
Pfizer, Inc.	Gibsonburg, OH	Rotary kiln Materials transfer Product loading	PM	1980	7
Standard Lime	Woodville, OH	Rotary kiln	PM, NO_x, CO_2	1975	8
Dow Chemical	Freeport, TX	Rotary kiln	PM, NO_x, CO_2	1974	9
J. E. Baker	Millersville, OH	Rotary kiln	PM, SO_2, SO3, CO_2	1974	10
J. E. Baker	Millersville, OH	Rotary kiln	PM, SO_2, CO_2	1975	11
Paul Lime Plant	Millersville, OH	Rotary kiln	PM	1975	12
U.S. Lime	Nelson, AZ	Rotary kiln	PM, SO_2, CO_2	1975	13
Allied Products	Montevallo, AL	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1975	14
Martin-Marietta	Calera, AL	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1975	15
		Atmospheric hydrator	PM		
Plant No. 1		Rotary kiln	PM, CO_2	1977	16
Plant No. 2		Rotary kiln	PM, CO_2	1977	17
Plant No. 3		Rotary kiln	PM, CO_2	1977	18
U.S. Lime	City of Industry, CA	Atmospheric hydrator	PM, CO_2	1974	19
National Lime and Stone	Carey, OH	Calcimatic kiln	PM, NO_x, CO_2	1974	20
		Cooler	PM, CO_2		
Martin-Marietta	Woodville, OH	Rotary kiln	SO_2, CO_2	1976	21
		Rotary kiln with preheater	CO_2		

TABLE 4-1. (continued)

Company name	Plant location	Sources tested	Pollutants	Year	Ref.
J. E. Baker	Millersville, OH	Rotary kiln	SO_2, CO, CO_2	1975	22
Allied Products	Alabaster, AL	Rotary kiln	PM, CO_2	1990	23
Allied Products	Alabaster, AL	Rotary kiln	PM, CO_2	1991	24
Dravo Lime	Saginaw, AL	Rotary kiln	PM, CO_2	1986	25
Dravo Lime	Saginaw, AL	Rotary kiln	PM, SO_2, NO_x, CO_2	1991	26
Paul Lime Co.	Douglas, AZ	Rotary kiln	PM	1972	27
Bethlehem Mines	Annville, PA	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1974	28
Marblehead Lime	Gary, IN	Rotary kiln	PM, SO_2, NO_x, CO, CO_2	1974	29
Allied Products	Alabaster, AL	Rotary kiln	PM, CO_2	1974	30
J. E. Baker	Millersville, OH	Rotary kiln	PM	1975	31
Chemstar Lime Co.	Bancroft, ID	Six raw material processing sources	PM	1993	50
		Parallel flow regenerative kiln	PM, SO_2, NO_x, CO		

TABLE 4-3. SUMMARY OF TEST DATA FOR LIME MANUFACTURING

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (coal-fired)	None	PM, filterable	5	130-200 (270-410)	170 (330)	A	6
Rotary kiln (coal-fired)	None	PM, filterable	16	110-300 (210-590)	190 (370)	A	7
Rotary kiln (coal-fired)	Large-diameter cyclone	PM, filterable	15	34-80 (68-160)	60 (120)	A	7
Rotary kiln (coal-fired)	Large- diameter cyclone	PM, filterable	2	97-110 (190-210)	100 (200)	C	8
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	12	0.026-0.072 (0.052-0.14)	0.049 (0.097)	A	7
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	3	0.23-0.31 (0.46-0.63)	0.28 (0.56)	C	28
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	6	0.23-0.70 (0.45-1.4)	0.41 (0.83)	D	17
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	2	0.55-0.56 (1.1)	0.55 (1.1)	D	3
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	6	0.64-1.5 (1.6-3.0)	0.98 (2.0)	D	16
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	3	0.41-0.63 (0.82-1.3)	0.51 (1.0)	D	18
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	2	0.070-0.10 (0.14-0.21)	0.087 (0.17)	C	15
Rotary kiln (coal-fired)	Fabric filter	PM, filterable	3	0.12-0.13 (0.25)	0.13 (0.25)	B	26
Rotary kiln (coal-fired)	ESP	PM, filterable	16	2.1-6.1 (4.4-12.1)	4.3 (8.5)	A	7
Rotary kiln (coal-fired)[c]	Venturi scrubber	PM, filterable	3	0.30-0.51 (0.60-1.0)	0.46 (0.93)	D	31
Rotary kiln (coal-fired)[c]	Venturi scrubber	PM, filterable	3	2.4-6.5 (4.7-13)	4.1 (8.2)	C	11
Rotary kiln (coal-fired)[d]	Venturi scrubber	PM, filterable	3	1.8-2.3 (3.5-4.7)	2.0 (4.0)	C	10
Rotary kiln (coal-fired)[d]	Venturi scrubber	PM, filterable	3	1.1-1.2 (2.2-2.5)	1.2 (2.4)	B	5
Rotary kiln (coal-fired)	Venturi scrubber	PM, filterable	3	0.47-0.64 (0.94-1.3)	0.55 (1.1)	B	24
Rotary kiln (coal-fired)[e]	Venturi scrubber	PM, filterable	3	0.35-0.50 (0.71-1.0)	0.41 (0.82)	B	23
Rotary kiln (coal-fired)	None	PM, condensible inorganic	3	0.57-1.5 (1.1-2.9)	0.90 (1.8)	C	6
Rotary kiln (coal-fired)	Large-diameter cyclone	PM, condensible inorganic	2	0.30-0.57 (0.61-1.1)	0.43 (0.87)	C	8
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	2	0.077-0.080 (0.16-0.16)	0.079 (0.16)	C	15
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	3	0.032-.039 (0.064-0.079)	0.035 (0.070)	C	28

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	6	0.13-0.38 (0.25-0.75)	0.22 (0.45)	D	16
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	3	0.026-0.10 (0.052-0.21)	0.058 (0.12)	D	18
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	6	0.067-1.4 (0.13-2.8)	0.45 (0.90)	D	17
Rotary kiln (coal-fired)	Fabric filter	PM, condensible inorganic	2	0.14-0.18 (0.29-0.36)	0.16 (0.33)	D	3
Rotary kiln (coal-fired)[d]	Venturi scrubber	PM, condensible inorganic	3	0.027-0.20 (0.054-0.40)	0.12 (0.24)	B	5
Rotary kiln (coal-fired)[d]	Venturi scrubber	PM, condensible inorganic	3	0.20-0.47 (0.39-0.93)	0.33 (0.65)	C	10
Rotary kiln (coal-fired)[c]	Venturi scrubber	PM, condensible inorganic	3	0.030-0.090 (0.059-0.18)	0.055 (0.11)	C	11
Rotary kiln (coal-fired)[c]	Venturi scrubber	PM, condensible inorganic	3	0.20-0.27 (0.41-0.54)	0.24 (0.48)	D	31
Rotary kiln (coal-fired)	None	PM, condensible organic	3	0.32-0.81 (0.63-1.6)	0.51 (1.0)	C	6
Rotary kiln (coal-fired)[d]	None	PM, filterable and condensible inorganic	3	100-160 (200-330)	120 (250)	C	5
Rotary kiln (coal-fired)	None	SO_2	5	1.1-3.1 (2.2-6.2)	2.3 (4.6)	B	15
Rotary kiln (coal-fired)	None	SO_2	3	2.7-3.8 (4.3-7.7)	3.1 (6.2)	A	6
Rotary kiln (coal-fired)	Fabric filter	SO_2	3	0.11-0.26 (0.22-0.51)	0.18 (0.37)	C	28
Rotary kiln (coal-fired)	Fabric filter	SO_2	5	1.1-3.1 (2.2-6.2)	2.3 (4.6)	B	15
Rotary kiln (coal-fired)	Fabric filter	SO_2	1[f]	5.3 (11)	5.3 (11)	D	15
Rotary kiln (coal-fired)	Fabric filter	SO_2	3	0.0044-0.0066 (0.0087-0.011)	0.0066 (0.013)	B	26
Rotary kiln (coal-fired)[d]	Venturi scrubber	SO_2	3	0.25-0.65 (0.50-1.3)	0.40 (0.79)	C	10
Rotary kiln (coal-fired)[c]	Venturi scrubber	SO_2	3	15-19 (30-38)	17 (34)	D	11
Rotary kiln (coal-fired)[d]	Settling chamber	SO_2	6	2.1-9.2 (4.2-18)	5.8 (12)	C	22
Rotary kiln (coal-fired)[d]	Settling chamber/wet scrubber	SO_2	5	0.049-0.20 (0.10-0.40)	0.076 (0.15)	B	22

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (coal-fired)[c]	Settling chamber/wet scrubber	SO_2	6	0.17-0.30 (0.33-0.64)	0.23 (0.45)	B	22
Rotary kiln (coal-fired)[c]	Settling chamber	SO_2	6	5.2-6.6 (10-13)	5.9 (12)	C	22
Rotary kiln (coal-fired)	None	NO_x	3	0.20-1.0 (0.40-2.0)	0.56 (1.1)	A	8
Rotary kiln (coal-fired)	None	NO_x	12	0.73-2.3 (1.5-4.5)	1.6 (3.2)	A	6
Rotary kiln (coal-fired)	Fabric filter	NO_x	3	1.7-2.0 (3.3-3.6)	1.8 (3.6)	C	28
Rotary kiln (coal-fired)	Fabric filter	NO_x	23	2.0-3.5 (4.0-7.0)	2.7 (5.3)	B	15
Rotary kiln (coal-fired)	Fabric filter	NO_x	3	1.0-1.1 (2.0-2.2)	1.1 (2.1)	B	26
Rotary kiln (coal-fired)	None	CO	2	25-27 (50-54)	26 (52)	D	6
Rotary kiln (coal-fired)	Fabric filter	CO	4	0.11-0.83 (0.22-1.7)	0.38 (0.76)	B	15
Rotary kiln (coal-fired)	Fabric filter	CO	3	0.046-0.088 (0.093-0.18)	0.061 (0.12)	D	28
Rotary kiln (coal-fired)[d]	Settling chamber/wet scrubber	CO	8	0.53-4.0 (1.1-8.1)	1.4 (2.7)	C	22
Rotary kiln (coal-fired)[c]	Settling chamber	CO	4	0.25-0.55 (0.49-1.1)	0.45 (0.90)	C	22
Rotary kiln (coal-fired)	None	CO_2	2	2,200-2,200 (4,500-4,500)	2,200 (4,500)	C	8
Rotary kiln (coal-fired)[d]	None	CO_2	1	2,100-2,800 (4,300-5,500)	2,500 (4,900)	C	5
Rotary kiln (coal-fired)	None	CO_2	5	710-1,500 (1,400-3,000)	1,300 (2,500)	A	6
Rotary kiln (coal-fired)	Fabric filter	CO_2	3	1,200-1,300 (2,400-2,700)	1,300 (2,500)	C	28
Rotary kiln (coal-fired)	Fabric filter	CO_2	3	not available	1,500 (3,100)	C	18
Rotary kiln (coal-fired)	Fabric filter	CO_2	3	not available	970 (1,900)	D	17
Rotary kiln (coal-fired)	Fabric filter	CO_2	2	1,100-1,100 (2,100-2,200)	1,100 (2,200)	C	15
Rotary kiln (coal-fired)	Fabric filter	CO_2	6	1,500-1,600 (3,100-3,300)	1,600 (3,200)	D	16
Rotary kiln (coal-fired)	Fabric filter	CO_2	3	1,400-1,500 (2,700-3,100)	1,500 (3,000)	B	26
Rotary kiln (coal-fired)	Venturi scrubber	CO_2	3	1,600-1,800 (3,200-3,600)	1,700 (3,400)	B	24
Rotary kiln (coal-fired)[e]	Venturi scrubber	CO_2	3	1,400-1,500 (2,900-3,000)	1,500 (3,000)	B	23
Rotary kiln (coal-fired)[d]	Venturi scrubber	CO_2	1	2,500 (4,900)	2,500 (4,900)	B	5

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (coal-fired)[d]	Venturi scrubber	CO_2	3	2,300-2,600 (4,600-5,200)	2,500 (5,000)	C	10
Rotary kiln (coal-fired)[c]	Settling chamber	CO_2	4	1,100-1,700 (2,100-3,400)	1,400 (2,700)	B	22
Rotary kiln (coal-fired)	Settling chamber	CO_2	10	360-1,300 (730-2,500)	940 (1,900)	B	21
Rotary kiln (coal-fired)[d]	Settling chamber/wet scrubber	CO_2	4	1,900-2,300 (3,900-4,600)	2,100 (4,200)	B	22
Rotary kiln (coal-fired)[d]	Settling chamber	CO_2	5	1,700 (3,300-3,400)	1,700 (3,400)	B	22
Rotary kiln (coal-fired)[d]	Venturi scrubber	SO_3	3	0.10-0.12 (0.20-0.24)	0.11 (0.21)	C	10
Rotary kiln (gas-fired)	ESP	PM, filterable	2	0.059-0.11 (0.12-0.22)	0.086 (0.17)	C	9
Rotary kiln (gas-fired)	Gravel bed filter	PM, filterable	3	0.38-0.50 (0.76-1.0)	0.44 (0.87)	C	12
Rotary kiln (gas-fired)	Gravel bed filter	PM, filterable	2	0.56-0.58 (1.1-1.2)	0.57 (1.1)	D	27
Rotary kiln (gas-fired)	ESP	PM, condensible inorganic	2	0.085-0.13 (0.17-0.27)	0.11 (0.22)	C	9
Rotary kiln (gas-fired)	Gravel bed filter	PM, condensible inorganic	3	0.0036-0.051 (0.0072-0.10)	0.022 (0.045)	D	12
Rotary kiln (gas-fired)	Gravel bed filter	PM, condensible inorganic	2	0.45-0.46 (0.90-0.92)	0.46 (0.91)	D	27
Rotary kiln (gas-fired)	ESP	NO_x	3	1.4-2.1 (2.8-4.2)	1.7 (3.5)	C	9
Rotary kiln (gas-fired)	ESP	CO	3	0.29-2.6 (0.59-5.1)	1.1 (2.2)	C	9
Rotary kiln (50/50 coal-, gas-fired)[e]	None	PM, filterable	2	24-56 (48-110)	40 (80)	D	30
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	PM, filterable	3	0.35-0.48 (0.69-0.97)	0.44 (0.87)	B	14
Rotary kiln (50/50 coal-, gas-fired)[e]	Venturi scrubber	PM, filterable	3	0.24-0.37 (0.49-0.74)	0.33 (0.65)	D	30
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	PM, condensible inorganic	3	0.032-0.051 (0.064-0.10)	0.041 (0.082)	B	14
Rotary kiln (60% coal-, 40% gas-fired)	None	SO_2	1[g]	1.4-2.7 (2.0-5.5)	1.9 (3.9)	D	14
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	NO_x	3	1.2-1.6 (2.3-3.2)	1.4 (2.7)	B	14

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	CO	3	0.14-0.82 (0.28-1.6)	0.41 (0.83)	B	14
Rotary kiln (60% coal-, 40% gas-fired)	Multiclone/venturi scrubber	CO_2	3	1,600-1,600 (3,200-3,300)	1,600 (3,200)	B	14
Rotary kiln (50/50 coal-, gas-fired)[e]	Venturi scrubber	CO_2	1	690 (1,400)	690 (1,400)	D	30
Rotary kiln (70% coke-, 30% coal-fired)	Venturi scrubber	PM, filterable	3	0.81-0.86 (1.6-1.7)	0.83 (1.7)	B	25
Rotary kiln (70% coke-, 30% coal-fired)	Venturi scrubber	CO_2	3	1,500-1,600 (3,000-3,200)	1,500 (3,000)	B	25
Rotary kiln with preheater (coal-fired)	Multiclone	PM, filterable	2	19-65 (38-130)	42 (84)	C	8
Rotary kiln with preheater (coal-fired)	Gravel bed filter	PM, filterable	3	0.57-0.61 (1.1-1.2)	0.59 (1.2)	C	13
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	PM, filterable	6	0.30-0.72 (0.61-1.4)	0.56 (1.1)	C	29
Rotary kiln with preheater (coal-fired)	Multiclone	PM, condensible inorganic	2	0.039-0.042 (0.078-0.083)	0.040 (0.081)	C	8
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	PM, condensible inorganic	6	0.40-0.68 (0.79-1.4)	0.57 (1.1)	C	29
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	PM, condensible organic	6	0.0099-0.14 (0.020-0.27)	0.076 (0.15)	C	29
Rotary kiln with preheater (coal-fired)	Gravel bed filter	SO_2	2	0.026-0.63 (0.052-1.3)	0.33 (0.65)	C	13
Rotary kiln with preheater (coal-fired)	Settling chamber/ fabric filter	SO_2	6	1.2-2.8 (2.4-5.6)	1.9 (3.9)	C	21
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	SO_2	6	3.0-3.9 (6.0-7.8)	3.2 (6.4)	C	29
Rotary kiln with preheater (coal-fired)	None	NO_x	3	2.2-2.3 (4.4-4.6)	2.3 (4.5)	A	8
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	NO_x	12	0.83-2.3 (1.7-4.5)	1.1 (2.2)	C	29
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	CO	3	0.24-8.7 (0.48-17)	3.2 (6.3)	D	29

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Rotary kiln with preheater (coal-fired)	None	CO_2	2	1,400-1,400 (2,800-2,800)	1,400 (2,800)	C	8
Rotary kiln with preheater (coal-fired)	Gravel bed filter	CO_2	2	2,500-2,600 (4,900-5,300)	2,500 (5,100)	C	13
Rotary kiln with preheater (coal-fired)	Settling chamber	CO_2	8	1,100-2,200 (2,100-4,300)	1,600 (3,200)	B	21
Rotary kiln with preheater (coal-fired)	Settling chamber	CO_2	7	600-1,100 (1,200-2,300)	840 (1,700)	B	21
Rotary kiln with preheater (coal-fired)	Settling chamber/ fabric filter	CO_2	3	1,100-1,200 (2,200-2,400)	1,100 (2,300)	B	21
Rotary kiln with preheater (coal-fired)	Multiclone/water spray/fabric filter	CO_2	6	1,600-1,900 (3,200-3,800)	1,700 (3,400)	C	29
Calcimatic kiln (gas-fired)	None	PM, filterable	2	83-92 (170-190)	88 (180)	D	20
Calcimatic kiln (gas-fired)	None	PM, filterable	2	6.8-7.0 (14-14)	7 (14)	D	20
Calcimatic kiln (gas-fired)	None	PM, condensible inorganic	2	0.036-0.10 (0.072-0.19)	0.066 (0.13)	D	20
Calcimatic kiln (gas-fired)	None	PM, condensible inorganic	2	0.18-0.23 (0.37-0.46)	0.21 (0.41)	C	20
Calcimatic kiln (gas-fired)	None	NO_x	5	0.039-0.095 (0.079-0.19)	0.076 (0.15)	A	20
Calcimatic kiln (gas-fired)	None	CO_2	2	2,000 (4,000-4,100)	2,000 (4,000)	C	20
Calcimatic kiln (gas-fired)	None	CO_2	2	670-690 (1,300-1,400)	680 (1,400)	C	20
Parallel flow regenerative kiln (gas-fired)	Fabric filter	PM, filterable	3	0.022-0.028 (0.044-0.056)	0.026 (0.051)	A	50
Parallel flow regenerative kiln (gas-fired)	Fabric filter	SO_2	3	0.00040-0.00080 (0.00079-0.0016)	0.00060 (0.0012)	A	50
Parallel flow regenerative kiln (gas-fired)	Fabric filter	NO_x	3	0.11-0.12 (0.22-0.24)	0.12 (0.024)	A	50
Parallel flow regenerative kiln (gas-fired)	Fabric filter	CO	3	0.21-0.24 (0.41-0.48)	0.23 (0.45)	A	50
Atmospheric hydrator	Wet scrubber	PM, filterable	2	0.026-0.043 (0.052-0.086)	0.033 (0.067)	B	19
Atmospheric hydrator	Wet scrubber	PM, filterable	3	0.066-0.17 (0.13-0.35)	0.087 (0.17)	C	15

TABLE 4-3. (continued)

Source	Control	Pollutant[a]	No. of runs	EF range, kg/Mg (lb/ton)[b]	EF average, kg/Mg (lb/ton)[b]	Data rating	Ref. No.
Atmospheric hydrator	Wet scrubber	PM, condensible inorganic	2	0.0046-0.0091 (0.0091-0.018)	0.0067 (0.013)	B	19
Atmospheric hydrator	Wet scrubber	PM, condensible inorganic	3	0.010-0.079 (0.0071-0.021)	0.0069 (0.014)	C	15
Cooler	None	PM, filterable	2	2.4-4.5 (4.7-9.0)	3.4 (6.8)	C	20
Cooler	None	PM, condensible inorganic	2	0.0049-0.018 (0.010-0.036)	0.011 (0.023)	C	20
Cooler	None	CO_2	2	3.8-4.0 (7.6-8.0)	3.9 (7.8)	C	20
Final sizing screens	Fabric filter	PM, filterable	1	0.0012 (0.0023)	0.0012 (0.0023)	unrated	2
Primary crusher	None	PM, filterable	2	0.0076-0.0090 (0.015-0.0018)	0.0083 (0.017)	C	2
Primary crusher, screen, and hammermill	Fabric filter	PM, filterable	2	0.00020-0.00069 (0.00040-0.0014)	0.00044 (0.00089)	C	2
Scalping screen and hammermill	None	PM, filterable	2	0.00029-0.62 (0.00058-1.2)	0.31 (0.62)	D	2
Primary crushing[h]	Fabric filter	PM, filterable	3	0.00019-0.00023 (0.00039-0.00046)	0.00021 (0.00043)	A	50
Primary screening[i]	Fabric filter	PM, filterable	3	0.00027-0.00034 (0.00054-0.00067)	0.00030 (0.00061)	A	50
Crushed material conveyor transfer[j]	Fabric filter	PM, filterable	6	($2.8x10^{-5}$-$8.1x10^{-5}$) ($5.6x10^{-5}$-0.00016)	$4.4x10^{-5}$ ($8.8x10^{-5}$)	A	50
Secondary and tertiary screening[k]	Fabric filter	PM, filterable	3	$4.8x10^{-5}$-$4.0x10^{-5}$ ($9.5x10^{-5}$-0.00016)	$6.5x10^{-5}$ (0.00013)	A	50
Material transfer and drop points	None	PM, filterable	16	0.54-1.7 (1.1-3.3)	1.1 (2.2)	C	7
Fugitive, product loading (enclosed truck)	None	PM, filterable	3	0.15-0.41 (0.30-0.82)	0.31 (0.61)	A	7
Fugitive, product loading (open truck)	None	PM, filterable	2	0.67-0.84 (1.3-1.7)	0.75 (1.50)	B	7

[a]Filterable PM is that PM collected on or prior to the filter for an EPA Method 5 (or equivalent) sampling train. Condensible PM is that PM collected in the impinger portion of a PM sampling train and analyzed by EPA Method 202. Emission factors for condensible PM include both organic and inorganic condensible PM. Total PM is that PM collected in the entire sampling train and analyzed by Methods 5 and 202.

[b]Emission factors for kilns, coolers, preheaters, and hydrators in units of mass of pollutant emitted per mass of lime produced; emission factors for crushing, screening, grinding, and loading in units of mass of pollutant emitted per mass of stone/lime feed.

[c]Tests conducted on the this kiln are also documented in other references as indicated.

[d]Tests conducted on the this kiln are also documented in other references as indicated.

[e]Tests conducted on the this kiln are also documented in other references as indicated.

[f]Multiple CEM readings.

[g]A total of 30 CEM readings over a 4-hour period.

[h]Includes scalping screen, scalping screen discharges, primary crusher, primary crusher discharges, and ore discharge.

[i]Includes primary screening, including the screen feed, screen discharge, and surge bin discharge.

[j]Based on average of three runs each of emissions from two conveyor transfer points on the conveyor from the primary crusher to the primary stockpile.

TABLE 4-3. (continued)

[k]Based on sum of emissions from two emission points that include conveyor transfer point for the primary stockpile underflow to the secondary screen, secondary screen, tertiary screen, and tertiary screen discharge.

TABLE 4-5. SUMMARY OF AVERAGE EMISSION FACTORS FOR LIME MANUFACTURING[a]

Source	Type of control	Pollutant	No. of tests	Emission factor, kg/Mg	Emission factor, lb/ton	Rating	References
Rotary kiln (coal-fired)	None	Filterable PM	2	180	350	D	6, 7
Rotary kiln (coal-fired)	None	Filterable PM-10	b	22	42	D	1, 6, 7
Rotary kiln (coal-fired)	Large diam. cyclone	Filterable PM	1	60	120	D	7
Rotary kiln (coal-fired)	Fabric filter	Filterable PM	4	0.14	0.28	D	7, 15, 26, 28
Rotary kiln (coal-fired)	Fabric filter	Filterable PM-10	b	0.077	0.15	D	1, 7, 15, 26, 28
Rotary kiln (coal-fired)	ESP	Filterable PM	1	4.3	8.5	D	7
Rotary kiln (coal-fired)	ESP	Filterable PM-10	b	2.2	4.3	D	1, 7
Rotary kiln (coal-fired)	Venturi scrubber	Filterable PM	3	0.72	1.4	D	5, 23, 24
Rotary kiln (coal-fired)	None	Condensible inorganic PM	2	0.67	1.3	E	6,8
Rotary kiln (coal-fired)	Fabric filter	Condensible inorganic PM	6	0.19	0.38	E	3, 15, 16, 17, 18, 28
Rotary kiln (coal-fired)	Venturi scrubber	Condensible inorganic PM	3	0.14	0.28	D	5, 10, 11
Rotary kiln (coal-fired)	None	Condensible organic PM	1	0.51	1.0	E	6
Rotary kiln (coal-fired)	None	SO_2	2	2.7	5.4	D	6, 15
Rotary kiln (coal-fired)	Fabric filter	SO_2	3	0.83	0.17	D	15, 26, 28
Rotary kiln (coal-fired)	Wet scrubber	SO_2	2	0.15	0.3	D	22
Rotary kiln (coal-fired)	None	NO_x	5	1.6	3.1	C	6, 8, 15, 26, 28
Rotary kiln (coal-fired)	None	CO	3	0.74	1.5	D	15, 22
Rotary kiln (coal-fired)	None	CO_2	9	1,600	3,200	C	5, 6, 21, 22, 23, 24, 26
Rotary kiln (coal-fired)	Venturi scrubber	SO_3	1	0.11	0.21	E	10
Rotary kiln (gas-fired)	ESP	Filterable PM	1	0.086	0.17	E	9
Rotary kiln (gas-fired)	Gravel bed	Filterable PM	2	0.51	0.99	E	12, 27
Rotary kiln (gas-fired)	ESP	Condensible inorganic PM	1	0.11	0.22	E	9
Rotary kiln (gas-fired)	Gravel bed filter	Condensible inorganic PM	1	0.24	0.48	E	12, 27
Rotary kiln (gas-fired)	None	NO_x	1	1.7	3.5	E	9
Rotary kiln (gas-fired)	None	CO	1	1.1	2.2	E	9
Rotary kiln (coal/gas-fired)	None	Filterable PM	1	40	80	E	14

TABLE 4-5. (continued)

Source	Type of control	Pollutant	No. of tests	Emission factor, kg/Mg	Emission factor, lb/ton	Rating	References
Rotary kiln (coal/gas-fired)	Venturi scrubber	Filterable PM	1	0.44	0.87	D	14
Rotary kiln (coal/gas-fired)	Venturi scrubber	Condensible inorganic PM	1	0.041	0.082	D	14
Rotary kiln (coal/gas-fired)	Venturi scrubber	NO_x	1	1.4	2.7	D	14
Rotary kiln (coal/gas-fired)	Venturi scrubber	CO	1	0.41	0.83	D	14
Rotary kiln (coal/gas-fired)	Venturi scrubber	CO_2	1	1,600	3,200	D	14
Rotary kiln (coal/coke-fired)	Venturi scrubber	Filterable PM	1	0.83	1.7	D	25
Rotary kiln (coal/coke-fired)	Venturi scrubber	CO_2	1	1,500	3,000	D	25
Rotary preheater kiln (coal-fired)	Multiclone	Filterable PM	1	42	84	E	8
Rotary preheater kiln (coal-fired)	Gravel bed filter	Filterable PM	1	0.59	1.2	E	13
Rotary preheater kiln (coal-fired)	Multiclone/ water spray/ fabric filter	PM, filterable	1	0.56	1.1	E	29
Rotary preheater kiln (coal-fired)	Multiclone/ water spray/ fabric filter	PM, condensible inorganic	1	0.57	1.1	E	29
Rotary preheater kiln (coal-fired)	Multiclone/ water spray/ fabric filter	PM, condensible organic	1	0.076	0.15	E	29
Rotary preheater kiln (coal-fired)	Multiclone	Condensible inorganic PM	1	0.040	0.081	E	8
Rotary preheater kiln (coal-fired)	Dry PM controls	SO_2	2	1.1	2.3	E	13, 21
Rotary preheater kiln (coal-fired)	Multiclone/ water spray/ fabric filter	SO_2	1	3.2	6.4	E	29
Rotary preheater kiln (coal-fired)	None	CO	1	3.2	6.3	E	29
Rotary preheater kiln (coal-fired)	None	CO_2	3	1,200	2,400	D	21
Calcimatic kiln (gas-fired)	None	Filterable PM	1	48	97	E	20
Calcimatic kiln (gas-fired)	None	Condensible inorganic PM	1	0.14	0.27	E	20

TABLE 4-5. (continued)

Source	Type of control	Pollutant	No. of tests	Emission factor, kg/Mg	Emission factor, lb/ton	Rating	References
Calcimatic kiln (gas-fired)	None	NO_x	1	0.076	0.15	D	20
Calcimatic kiln (gas-fired)	None	CO_2	1	1,300	2,700	E	20
Parallel flow regenerative kiln (gas-fired)	Fabric filter	PM, filterable	1	0.026	0.051	D	50
Parallel flow regenerative kiln (gas-fired)	Fabric filter	SO_2	1	0.00060	0.0012	D	50
Parallel flow regenerative kiln (gas-fired)	None	NO_x	1	0.12	0.24	D	50
Parallel flow regenerative kiln (gas-fired)	None	CO	1	0.23	0.45	D	50
Atmospheric hydrator	Wet scrubber	Filterable PM	1	0.033	0.067	D	19
Atmospheric hydrator	Wet scrubber	Condensible inorganic PM	1	0.0067	0.013	D	19
Cooler	None	Filterable PM	1	3.4	6.8	E	20
Cooler	None	Condensible inorganic PM	1	0.011	0.023	E	20
Cooler	None	CO_2	1	3.9	7.8	E	20
Primary crushing[c]	None	Filterable PM	1	0.0083	0.017	E	2
Scalping screen and hammermill[c]	None	Filterable PM	1	0.31	0.62	E	2
Primary crushing[d]	Fabric filter	PM, filterable	1	0.00021	0.00043	D	50
Primary screening[e]	Fabric filter	PM, filterable	1	0.00030	0.00061	D	50
Crushed material conveyor transfer[f]	Fabric filter	PM, filterable	1	$4.4x10^{-5}$	$8.8x10^{-5}$	D	50
Secondary and tertiary screening[g]	Fabric filter	PM, filterable	1	$6.5x10^{-5}$	0.00013	D	50
Product transfer and conveying[c]	None	Filterable PM	1	1.1	2.2	E	7
Product loading (enclosed truck)[c]	None	Filterable PM	1	0.31	0.61	D	7
Product loading (open truck)[c]	None	Filterable PM	1	0.75	1.5	D	7

TABLE 4-5. (continued)

[a]Emission factors in units of kg/Mg (lb/ton) of lime produced except where indicated.

[b]Based on average particle size distribution presented in Table 4-4.

[c]Emission factors in units of kg/Mg (lb/ton) of stone or product processed.

[d]Emission factors in units of kg/Mg (lb/ton) of material processed. Includes scalping screen, scalping screen discharges, primary crusher, primary crusher discharges, and ore discharge.

[e]Emission factors in units of kg/Mg (lb/ton) of material processed. Includes primary screening, including the screen feed, screen discharge, and surge bin discharge.

[f]Emission factors in units of kg/Mg (lb/ton) of material processed. Based on average of three runs each of emissions from two conveyor transfer points on the conveyor from the primary crusher to the primary stockpile.

[g]Emission factors in units of kg/Mg (lb/ton) of material processed. Based on sum of emissions from two emission points that include conveyor transfer point for the primary stockpile underflow to the secondary screen, secondary screen, tertiary screen, and tertiary screen discharge.