EPA-600/7-86-031
September 1986

LIME AND CEMENT INDUSTRY PARTICULATE EMISSIONS: SOURCE CATEGORY REPORT
VOLUME I. LIME INDUSTRY

by

John S. Kinsey
Midwest Research Institute
425 Volker Boulevard
Kansas City, Missouri 64110

EPA Contract No. 68-02-3999
Technical Directive No. 3

EPA Project Officer: Dale L. Harmon
Air and Energy Engineering Research Laboratory
Research Triangle Park, North Carolina 27711

Prepared for:

U.S. Environmental Protection Agency
Office of Research and Development
Washington, D.C. 20460

PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Environmental Protection Agency's (EPA's) Air and Energy Engineering Research Laboratory under EPA Contract No. 68-02-3999, Work Assignment No. 3. Dale Harmon was the Project Officer for this study. The work was performed in MRI's Air Quality Assessment Section (Chatten Cowherd, Head). John Kinsey was the author of the report. Gregory Muleski was responsible for the computer software used in the study, and Julia Poythress was involved in data compilation and analysis.

Volume I of the report contains the information related to the lime industry. Volume II contains the information related to the portland cement industry.

CONTENTS

FIGURES

TABLES

TABLES (continued)

TABLES (concluded)

SECTION 1.0

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is in the process of reviewing the pertinent technical criteria and data bases to determine whether a revised National Ambient Air Quality Standard (NAAQS) for particulate matter based on particle size is warranted. Upon adoption of such a standard, the Clean Air Act requires that each state develop and submit State Implementation Plan (SIP) revisions which outline how they will attain and maintain the standard. Any revisions to the SIP would necessitate the collection and use of information related to size-selective particulate emissions from new and existing sources.

Since 1972 the document entitled "Compilation of Air Pollutant Emission Factors" (AP-42) has been published by the EPA. This document contains a compendium of emission factor reports for the most significant emission source categories. Supplements to AP-42 have been published both for new source categories and for updating existing emission factors as more information about sources and the control of emissions has become available. Up to this point, however, little information has been provided in AP-42 with regard to particle size characteristics of particulate emissions. To address the requirement for size-specific emission factors, the EPA is conducting research to characterize emissions in the inhalable particulate (IP) size range for a variety of industrial sources.

This report reviews the existing particulate emission factor data base for lime plants, evaluates the available data and provides a revised AP-42 Section (8.15) for this industry. Included in the revised Section 8.15 are size-specific particulate emission factors for lime plants as derived from best available data.

This report is organized by section as follows:

Section 2.0 - Industry Description
Section 3.0 - General Data Review and Analysis Procedures
Section 4.0 - Particulate Emission Factor Development
Section 5.0 - Proposed AP-42 Section 8.15

SECTION 2.0

LIME INDUSTRY DESCRIPTION

2.1 INTRODUCTION AND INDUSTRY OVERVIEW

Lime is made by calcining limestone which contains more than 50% calcium carbonate. The raw stone is subjected to temperatures of about 1090°C (2000°F) and the carbonate breaks down chemically to release carbon dioxide.[1] The finished product, basically calcium oxide (CaO), is commonly called burnt lime, quench lime, or quicklime.

The term "lime" also has a broad connotation and is frequently employed in referring to limestone. According to precise definition, lime can only be a burned form: quicklime, hydrated lime, or hydraulic lime. Essentially, these products are oxides or hydroxides of calcium and magnesium, except hydraulic types in which the CaO and MgO are chemically combined with various impurities. In hydrated lime, the oxide is converted into a hydroxide by a process called slaking. Slaking involves an exothermic reaction in which water chemically combines with the lime. The reversible reactions for both high calcium and dolomitic types are[1]:

<u>Quicklime</u>

$$\underset{\substack{\text{high calcium}\\\text{limestone}}}{CaCO_3} + \text{heat} \rightleftarrows \underset{\substack{\text{high calcium}\\\text{quicklime}}}{CaO} + CO_2$$

$$\underset{\substack{\text{dolomitic}\\\text{limestone}}}{CaCO_3 \cdot MgCO_3} + \text{heat} \rightleftarrows \underset{\substack{\text{dolomitic}\\\text{quicklime}}}{CaO \cdot MgO} + 2CO_2$$

Hydrated lime

$$\underset{\text{high calcium quicklime}}{CaO + H_2O} \rightleftarrows \underset{\text{high calcium hydrate}}{Ca(OH)_2 + \text{heat}}$$

$$\underset{\text{dolomitic quicklime}}{CaO \cdot MgO + H_2O} \rightleftarrows \underset{\text{dolomitic hydrate}}{Ca(OH)_2 \cdot MgO + \text{heat}}$$

$$\underset{\text{dolomitic quicklime}}{CaO \cdot MgO + 2H_2O} \rightleftarrows \underset{\text{dolomitic hydrate}}{Ca(OH)_2 \cdot Mg(OH)_2 + \text{heat}}$$

Calcining at about 1090°C (2000°F) produces a soft, porous lime which is highly chemically reactive. Heating beyond this stage can result in lumps of inert, semivitrified material. This is known as "over-burned" or "dead burned" lime. This low reactive material is often used in the manufacture of refractory materials. If the raw material is not calcined sufficiently, lumps of calcium carbonate are left in the finished product which is referred to as "underburned" lime.

Most of the lime produced in the United States is in the form of quicklime with the primary use being in BOF steel making furnaces.[2] Table 2-1 shows the amount of each type of lime produced during 1980 with its eventual end uses shown in Table 2-2.[2]

TABLE 2-1. AMOUNT OF LIME SOLD OR USED BY PRODUCERS IN 1980[2]

Type of lime	Amount[a] 10^3 short tons	10^3 Mg
Quicklime	15,972	14,487
Hydrated lime	2,544	2,307
Dead-burned dolomite	494	448
Total	19,010	17,242

Source: U.S. Bureau of Mines, Minearals Yearbook 1980, U.S. Government Printing Office, Washington, D.C., 1981.

[a] 1 short ton = 2,000 lb; 1 Mg = 1 metric ton = 10^6 g

TABLE 2-2. LIME SOLD OR USED BY PRODUCERS IN 1980[a]

Use	Sold		Used		Total[b]	
	10^3 Short tons	10^3 Metric tons	10^3 Short tons	10^3 Metric tons	10^3 Short tons	10^3 Metric tons (Mg)
Agriculture	79	72	-	-	79	72
Construction						
Road stabilization	554	502	-	-	554	502
Soil stabilization[c]	170	154	-	-	170	154
Mason's lime	288	261	40	36	328	297
Finishing lime	99	90	-	-	99	90
Other construction uses	16	15	27	24	44	40
Total[b]	1,126	1,021	68	62	1,194	1,083
Chemical and industrial						
Steel, BOF	4,409	3,999	1,441	1,307	5,850	5,306
Water purification	1,487	1,349	9	8	1,496	1,357
Alkalies	6	5	1,167	1,058	1,173	1,064
Paper and pulp	1,039	942	116	105	1,156	1,048
Sugar refining	58	53	909	824	967	877
Sewage treatment	848	769	12	11	860	780
Steel, electric	755	685	34	31	789	716
Sulfur removal	743	674	-	-	743	674
Copper ore concentration	340	308	318	288	658	597
Magnesia from seawater or brine	W	W	W	W	648	588
Steel, open hearth	564	512	38	34	602	546
Acid mine water	419	380	70	63	490	444
Aluminum and bauxite	160	145	114	103	275	249
Magnesium metal	W	W	W	W	187	170
Calcium carbide	121	110	63	57	185	168
Glass	180	163	-	-	180	163
Precipitated calcium carbonate	65	59	47	43	112	102
Petrochemicals	99	90	-	-	99	90
Petroleum refining	59	54	-	-	59	54
Oil well drilling	39	35	-	-	39	35
Food products	37	34	-	-	37	34
Metallurgy, other	31	28	4	4	35	32
Oil and grease	32	29	-	-	32	29
Tanning	28	25	-	-	28	25
Ore concentration, other	18	16	-	-	18	16
Wire drawing	13	12	-	-	13	12
Brick, sand-lime	6	5	-	-	6	5
Fertilizer	5	5	-	-	5	5
Insecticides	3	3	-	-	3	3
Paint	2	2	-	-	2	2
Calcium silicate	-	-	-	-	-	-
Gelatin	-	-	-	-	-	-
Rubber	W	W	W	W	W	W
Other uses[d]	645	585	714	648	523	474
Total[b]	12,211	11,075	5,059	4,589	17,269	15,663
Refractory dolomite	420	381	75	68	494	448
Grand total[b]	13,836	12,549	5,201	4,717	19,037	17,267

W - Withheld to avoid disclosing company proprietary data; included in "Other uses."

[a] Excludes regenerated lime. Includes Puerto Rico. Reference 2.

[b] Data may not add to totals shown because of independent rounding.

[c] Includes road stabilization (1979).

[d] Includes chrome, coke and gas, explosives, manganese (1980), silica brick, other uses, and uses indicated by symbol W.

During 1980, more than 17 million metric tons (19 million short tons) of lime was produced in the United States at 153 plants.[2] Utilizing the latest information available (1974), the location of the various lime plants throughout the United States is shown on Figure 2-1 with a listing of each plant provided in Table 2-3.[3] As can be seen from the data contained in Table 2-3, a net decrease of 12 plants has occurred in the 6 year period between 1974 and 1980 with an overall drop in production of approximately 2.4 million metric tons (2.6 million short tons).[3]

Table 2-4 shows the distribution of lime production by size of plant during 1980. These data indicate that most plants fall within the 23,000 to 45,000 metric ton (25,000 to 50,000 short tons) capacity range with the majority of the lime being produced by larger plants with capacities ranging from 181,000 to 363,000 metric tons (200,000 to 400,000 short tons).

2.2 RAW MATERIAL

Bedded deposits of limestone and dolomite rock used in manufacturing lime are generally obtained from open pit quarries and underground mines by conventional methods. Limestone is a sedimentary rock composed of calcium carbonate ($CaCO_3$). Dolomite or dolomitic limestone contains magnesium as well as calcium. Although limestone deposits are found in every state in the United States, only a small portion is pure enough for industrial lime manufacture. In general, quarries are selected to furnish rock containing low percentages of alumina, silica, clay, or iron oxide. Lime manufacture requires stone of definite size ranges depending on the type of kiln used.

A small percentage (approximately 8%) of lime is manufactured from sea shells.[3] Oyster and clam shells are the remains of marine animals, consisting mostly of calcium carbonate. These shells are concentrated in reefs along certain coastal areas, particularly along the Gulf Coast. Shell is usually recovered by conventional dredging and washing operations.

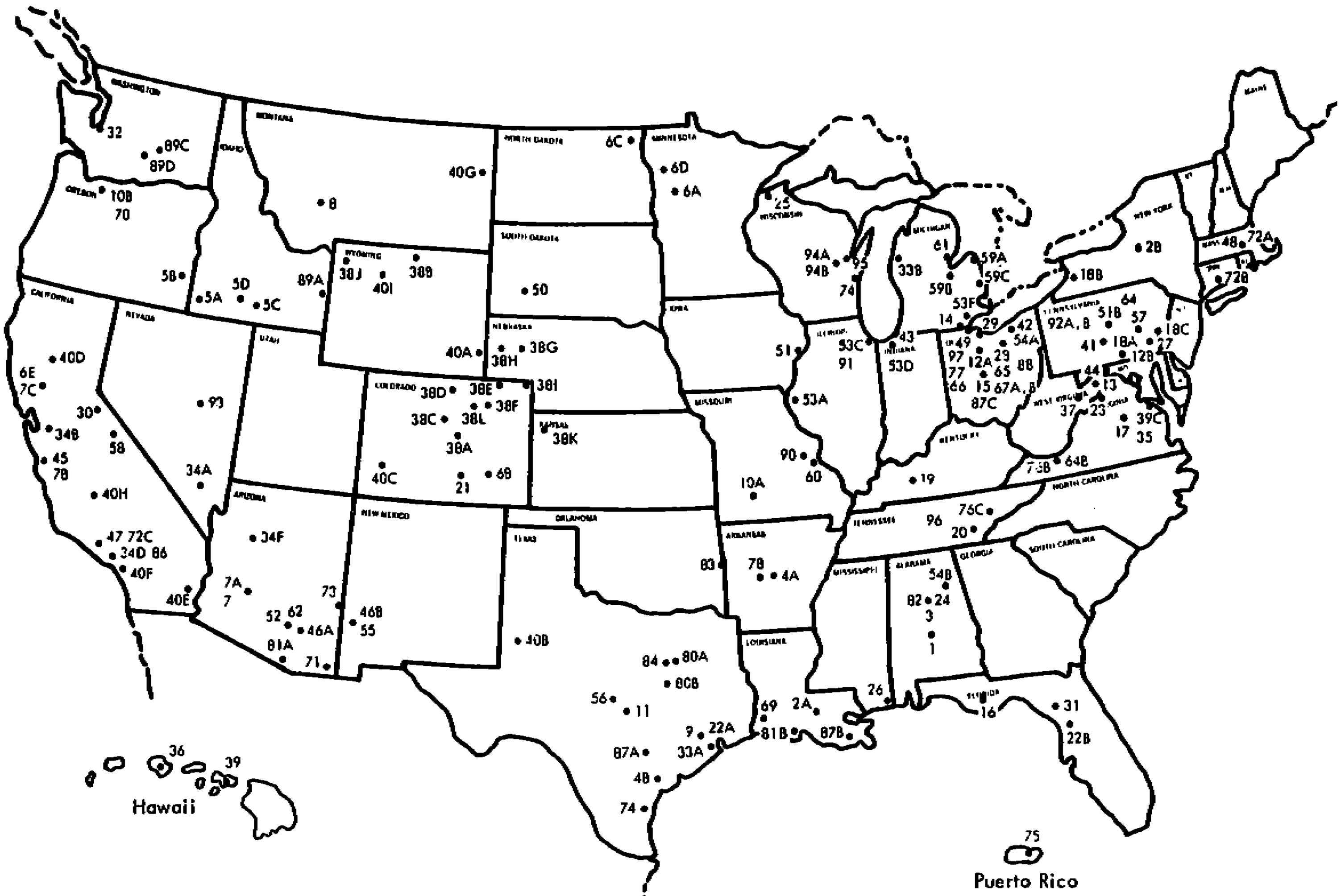

Figure 2-1. Geographical distribution of lime plants in the United States.

TABLE 2-3. OWNERSHIP AND LOCATION OF LIME PLANTS IN THE UNITED STATES (1974)[3]

Map ID No. (Figure 2-1)	Company	City or County, and State	Type of operation[a]
1 A	Alabaster Lime Company	Siluria, Alabama	Lime kiln and plant
2 A	Allied Chemical Corporation	East Baton Rouge, Co., Louisiana	Quarry and plant
B		Onondaga Co., New York	Plant
3	Allied Product Company	Montevallo, Alabama	
4 A	Aluminum Company of America	Saline Co., Arkansas	Plant
B		Calhoun Co., Texas	Plant
5 A	Amalgamated Sugar Company	Canyon Co., Idaho	
B		Malheur Co., Oregon	
C		Minidoka Co., Idaho	Plant
D		Twin Falls Co., Idaho	
6 A	American Crystal Sugar Company	Clay Co., Minnesota	Quicklime, shaft kilns
B		Otero Co., Colorado	Quicklime, shaft kilns
C		Pembina Co., North Dakota	Shaft kiln
D		Polk Co., Minnesota	Two plants, quicklime, shaft kilns
E		Yolo Co., California	Shaft kiln
7 A	Amstar Corporation	Maricopa Co., Arizona	
B		Monterey Co., California	Shaft and rotary kilns
C		Yolo Co., California	Shaft and rotary kilns
8	The Anaconda Company	Anaconda, Montana	Plant
9	Armco Steel Company	Harris Co., Texas	Plant
10 A	Ash Grove Cement Company	Greene Co., Missouri	Plant
B		Multnomah Co., Oregon	Plant
11	Austin White Lime Company	Travis Co., Texas	Plant
12 A	J. E. Baker Company	Sandusky Co., Ohio	Plant
B		York, Pennsylvania	Plant
13	S. W. Barrick & Sons, Inc.	Frederick Co., Maryland	Plant
14	BASF Wyandotte Corporation	Wayne Co., Michigan	Quicklime, nine shaft kilns
15	Basic, Inc.	Seneca Co., Ohio	Plant
16	Basic Magnesia, Inc.	Port St. Joe, Florida	Plant
17	Battery Park Fish and Oyster Corporation	Louisa Co., Virginia	
18 A	Bethlehem Steel Corporation	Adams Co., Pennsylvania	Quarry
B		Erie Co., New York	Plant
C		Lebanon Co., Pennsylvania	Plant
19	Black River Mining Company	Butler, Kentucky	
20	Bowaters Southern Paper Corporation	McMinn Co., Tennessee	
21	C F & I Steel Corporation	Pueblo, Colorado	Natural-frequency-vibrating kiln plant

(continued)

TABLE 2-3 (continued)

Map ID No. (Figure 2-1)	Company	City or County, and State	Type of operation[a]
22 A	Champion International	Harris Co., Texas	227 ton/day rotary kiln, hydrating facilities
B		Hernando Co., Florida	Plant
23	Chemstone Corporation	Shenandoah Co., Virginia	Plant
24	Cheney Lime and Cement Company	Shelby Co., Alabama	Lime kiln and plant
25	C L M Corporation	Douglas Co., Wisconsin	Quicklime and hydrated lime, 2 rotary kilns, 1 continuous hydrator
26	Corchem, Inc.	Jackson Co., Mississippi	Plant
27	G & W H Corson, Inc.	Montgomery Co., Pennsylvania	
28	Cuyahoga Lime Company	Cuyahoga Co., Ohio	Plant
29	Diamond Shamrock Company	Lake Co., Ohio	Plant
30	Diamond Springs Lime Company	El Dorado Co., California	Rotary kiln and continuous hydrator
31	Dixie Lime and Stone Company	Sumterville, Florida	Plant
32	Domtar Chemicals, Inc.	Pierce Co., Washington	Plant
33 A	Dow Chemical, U.S.A.	Brazoria Co., Texas	Quicklime, 3 rotary kilns, continuous hydrator
B		Mason Co., Michigan	Quicklime, 3 rotary kilns, continuous hydrator
34 A	The Flintkote Company	Clark Co., Nevada	2 plants, batch and continuous hydrators, rotary kilns
B		Contra Costa Co., California	Shaft and rotary kilns
C		Frederick Co., Virginia	Plant
D		Los Angeles Co., California	Shaft and rotary kilns
E		Tooele Co., Utah	2 shaft kiln plants
F		Yavapai Co., Arizona	
35	W. S. Frey Company, Inc.	Frederick Co., Virginia	Plant
36	Gaspro, Ltd.	Honolulu Co., Hawaii	Plant
37	Germany Valley Limestone Company	Pendleton Co., West Virginia	Plant
38 A	Great Western United Corporation	Adams Co., Colorado	Pot-kiln plant
B		Big Horn Co., Wyoming	Pot-kiln plant
C		Boulder Co., Colorado	2 pot-kiln plants
D		Larimer Co., Colorado	2 pot kiln plants
E		Logan Co., Colorado	Pot-kiln plant
F		Morgan Co., Colorado	Shaft-kiln plant
G		Morrill Co., Nebraska	Pot-kiln
H		Scottsbluff Co., Nebraska	3 plants, 5 pot-kilns
I		Sedgwick Co., Colorado	Pot-kiln plant
J		Yellowstone Co., Montana	
K		Sherman Co., Kansas	Plant
L		Weld Co., Colorado	2 pot-kiln plants
39	Hawaiian Commercial and Sugar Company, Ltd.	Maui Co., Hawaii	Rotary kiln and continuous hydrator

(continued)

TABLE 2-3 (continued)

Map ID No. (Figure 2-1)	Company	City or County, and State	Type of operation[a]
40 A	Holly Sugar Corporation	Goshen Co., Wyoming	Shaft kiln
B		Deaf Smith Co., Texas	
C		Delta Co., Colorado	
D		Glenn Co., California	Shaft kilns
E		Imperial Co., California	Shaft kilns
F		Orange Co., California	Shaft kilns
G		Richland Co., Montana	
H		San Joaquin, California	Shaft kilns
I		Washokie Co., Wyoming	
41	Honey Creek Lime Company	Mifflin Co., Pennsylvania	
42	Huron Lime Company	Erie Co., Ohio	Plant
43	Inland Steel Company	Lake Co., Indiana	
44	Jones & Laughlin Steel Corporation	Berkeley Co., West Virginia	Plant
45	Kaiser Aluminum and Chemical	Monterey Co., California	Rotary kiln and continuout hydrator
46 A	Kennecott Copper Corporation	Gila Co., Arizona	
B		Grant Co., New Mexico	Rotary kiln
C		Salt Lake Co., Utah	Lime kiln
47	Kerr-McGee Chemical Corporation	San Bernardino Co., California	
48	Lee Lime Corporation	Berkshire Co., Massachusetts	Plant
49	Edward C. Levy Company	Wayne Co., Michigan	Quicklime, shaft and rotary kilns
50	Pete Lien & Sons	Pennington Co., South Dakota	1 rotary kiln, 1 vertical kiln, continuous hydrator
51	Linwood Stone Products Company, Inc.	Scott Co., Iowa	Quicklime and hydrated lime, 3 rotary kilns
52	Magma Copper Company	Pinal Co., Arizona	
53 A	Marblehead Lime Company	Adams Co., Illinois	Quicklime and hydrated lime, 3 shaft kilns, 1 calcimatic kiln
B		Centre Co., Pennsylvania	
C		Cook Co., Illinois	Quicklime and hydrated lime, 8 rotary kilns
D		Lake Co., Indiana	Quicklime, 3 rotary kilns
E		Tooele Co., Utah	Rotary kiln
F		Wayne Co., Michigan	Quicklime, 2 rotary kilns
54 A	Martin-Marietta Corporation	Sandusky Co., Ohio	Plant
B		Shelby Co., Alabama	
55	Mathis Mining & Exploration	Grant Co., New Mexico	
56	McDonough Brothers, Inc.	Bexar Co., Texas	Plant
57	Mercer Lime and Stone Company	Butler Co., Pennsylvania	Plant
58	Merck Chemical Company	Tuolumne Co., California	

(continued)

TABLE 2-3 (continued)

Map ID No. (Figure 2-1)	Company	City or County, and State	Type of operation[a]
59 A	Michigan Sugar Company	Huron Co., Michigan	
B		Saginaw Co., Michigan	
C		Sanilac Co., Michigan	
D		Tuscola Co., Michigan	
60	Mississippi Lime Company	St. Genevieve Co., Missouri	Plant
61	Monitor Sugar Company	Bay Co., Michigan	
62	Corley L. Moore Lime Plant	Gilo Co., Arizona	
63	Mountain States Lime, Inc.	Utah Co., Utah	
64 A	National Gypsum Company	Centre Co., Pennsylvania	Plant
B		Giles Co., Virginia	Plant
65	Steeple & Company	Sandusky Co., Ohio	
66	National Lime and Stone Company	Wayandot Co., Ohio	Plant
67 A	Northern Ohio Sugar Company	Hancock Co., Ohio	
B		Sandusky Co., Ohio	
68	Ohio Lime Company	Sandusky Co., Ohio	Plant
69	Olin Corporation	Calcasieu Co., Louisiana	Quarry and plant
70	Pacific Carbide and Alloys Company	Multnomah Co., Oregon	Plant
71	Paul Lime Plant, Inc.	Cochise Co., Arizona	5 rotary kiln plants
72 A	Pfizer, Inc.	Berkshire Co., Massachusetts	Plant
B		Litchfield Co., Connecticut	Plant
C		San Bernardino Co., California	Fluidized-bed kiln and continuous hydrator
D		Sandusky Co., Ohio	Plant
73	Phelps Dodge Corporation	Greenlee Co., Arizona	1 rotary kiln, 1 fluidized-bed kiln plant
74	PPG Industries, Inc.	Nueces Co., Texas	Plant
75	Puerto Rican Cement Company, Inc.	Ponce Puerto Rico	
76 A	Rangaire Corporation	Independence Co., Arkansas	Plant
B		Giles Co., Virginia	Plant
C		Knox Co., Tennessee	Plant
77	Republic Steel Corporation	Lake Co., Ohio	Plant
78	Reynolds Metals Company	Saline Co., Arkansas	Plant
79	Rockwell Lime Company	Manitowoc, Wisconsin	Quicklime and hydrated lime, 1 rotary kiln, 1 continuous hydrator
80 A	Round Rock Lime Company	Hill Co., Texas	Plant
B		Williamson Co., Texas	Plant
81 A	Santa Rita Mining Company	Pima Co., Arizona	Mine and calciner
B		St. Mary Co., Louisiana	

(continued)

TABLE 2-3 (continued)

Map ID No. (Figure 2-1)	Company	City or County, and State	Type of operation[a]
82	S. I. Lime Company	Shelby Co., Alabama	
83	St. Clair Lime Company	Sequoyah Co., Oklahoma	Quarry and plant
84	Texas Lime Company	Johnson Co., Texas	Plant
85	Union Carbide Corporation	Ashtabula Co., Ohio	Plant
86	Union Sugar Company	Santa Barbara Co., California	Shaft kiln
87 A	U.S. Gypsum Company	Comal Co., Texas	Plant
B		Orleans Co., Louisiana	Quarry and plant
C		Ottawa Co., Ohio	Plant
88	U.S. Steel Corporation	Lorain Co., Ohio	Plant
89 A	Utah-Idaho Sugar Company	Bonneville Co., Idaho	
B		Box Elder Co., Utah	
C		Grant Co., Washington	
D		Yakima Co., Washington	
90	Valley Mineral Products Corporation	St. Francois Co., Missouri	Plant
91	Vulcan Materials Company	Cook Co., Illinois	
92 A	Warner Company	Center Co., Pennsylvania	Plant
B		Chester Co., Pennsylvania	Plant
93	Weatherly and Morrison Lime Company	White Pine Co., Nevada	Rotary kilns
94 A	Western Lime and Cement Company	Brown Co., Wisconsin	Quicklime and hydrated lime, 5 rotary kilns, 1 batch hydrator
B		Dodge Co., Wisconsin	Hydrated lime, 5 shaft kilns, 1 continuous hydrator
95		Fond DuLac Co., Wisconsin	Quick and hydrated lime, 5 shaft kilns, 1 batch hydrator
96	Williams Lime Manufacturing Company	Knox Co., Tennessee	Plant
97	Woodville Lime and Chemical Company	Sandusky Co., Ohio	

[a] The following list of companies, comprising the lime industry, either make quicklime or dolomitic lime and may or may not make the hydrated versions. Information sources do not differentiate between the different producers. All producers generate carbon dioxide, but it is not known which ones recover the material beneficially.

TABLE 2-4. LIME SOLD OR USED BY PRODUCERS IN THE UNITED STATES IN 1980 BY SIZE OF PLANT[a]

Size of plant (short tons)	No. of plants	Quantity[b] 10^3 short tons	10^3 metric tons	Percent of total
Less than 10,000 tons	9	57	52	c
10,000 to 25,000 tons	29	461	418	2
25,000 to 50,000 tons	30	1,026	931	5
50,000 to 100,000 tons	25	1,810	1,642	10
100,000 to 200,000 tons	26	3,644	3,305	19
200,000 to 400,000 tons	28	7,192	6,523	38
More than 400,000 tons	7	4,847	4,396	25
Total	154	19,037	17,267	100[d]

[a] Excludes regenerated lime. Includes Puerto Rico. Reference 2.

[b] 1 short ton = 2,000 lb; 1 metric ton = 10^6 g = 1 Mg.

[c] Less than 0.5%.

[d] Data do not add to total shown because of independent rounding.

More than 90% of the limestone mines is from open-pit operations with the remainder from underground mines.[3] Most lime producers own their source of limestone and have ample reserves of ore.

To be classed as limestone, the rock must contain at least 50% calcium carbonate. It is called high-calcium limestone when the rock contains less than 5% magnesium carbonate. When the raw material contains 30 to 45% magnesium carbonate, it is referred to as dolomite or dolomitic limestone. Table 2-5 provides data on typical chemical analyses of eight different types of limestone found in the United States.[1]

TABLE 2-5. REPRESENTATIVE CHEMICAL ANALYSES OF DIFFERENT TYPES OF LIMESTONES[a] FOUND IN THE UNITED STATES

Chemical compound	Limestone sample (percent)[b] 1	2	3	4	5	6	7	8
CaO	54.54	38.90	41.84	31.20	29.45	45.65	55.28	52.48
MgO	0.59	2.72	1.94	20.45	21.12	7.07	0.46	0.59
CO_2	42.90	33.10	32.94	47.87	46.15	43.60	43.73	41.85
SiO_2	0.70	19.82	13.44	0.11	0.14	2.55	0.42	2.38
Al_2O_3	0.68	5.40	4.55	0.30	0.04	0.23	0.13	1.57
Fe_2O_3	0.08	1.60	0.56	0.19	0.10	0.20	0.05	0.56
SO_3[d]	0.31		0.33			0.33	0.01	
P_2O_5			0.22		0.05	0.04		
Na_2O	0.16		0.31	0.06	0.01	0.01		
K_2O			0.72		0.01	0.03		
H_2O			1.55		0.16	0.23		
Other			0.29		0.01	0.06	0.08	0.20

[a] Reference 1.

[b] 1 = Indiana high calcium stone
2 = Lehigh Valley, PA, "cement rock
3 = Pennsylvania "cement rock"
4 = Illinois Niagaran dolomitic stone
5 = Northwestern Ohio Niagaran dolomitic stone
6 = New York magnesian stone
7 = Virginia high calcium stone
8 = Kansas Cretaceous high calcium stone (chalk)

[c] Includes some Fe as FeO.

[d] Includes some elemental sulfur.

2.3 PROCESS DESCRIPTION

The process of producing the various forms of lime involves the following basic steps: stone extraction; stone processing; calcination and pulverization; and hydration. There are no two plants which are exactly alike. However, Figure 2-2 provides a simplified block flow diagram for the production of lime and limestone products.

As with most facilities in the mineral products industry, lime plants have two major categories of particulate emissions: those which are vented to the atmosphere through some type of stack, vent, or pipe (ducted sources) and those which are emitted directly from the source to the ambient air (fugitive sources) without the aid of such equipment. Ducted emissions are usually captured and transported by an industrial ventilation system with one or more fans or air movers and emitted to the atmosphere through a stack. Fugitive sources, on the other hand, can either be process fugitives, which are emissions associated with some form of physical or chemical change in the material being processed, or open dust sources where no such change occurs. The following is a description of each basic step in the lime manufacturing process as well as the emissions associated with each.

2.3.1 Stone Extraction

As stated previously, most stone is obtained by open-pit quarrying methods. Underground mining is pursued by some important operations, but the tonnage quarried exceeds that mined by nearly 20-fold. Quarries vary greatly in depth--from 4.5 to 7.5 m (15 to 25 ft) deep quarries of up to 60 m (200 ft).

The first step in quarrying is stripping of the soil and loose rock that overlays the limestone deposit. Very rarely is limestone discovered in bare outcrop. After the bedrock is exposed and clean, the next procedure is drilling and blasting. The improved productivity of the large rotary and percussion drilling rigs has been so impressive that these rigs largely have replaced lower capacity well and shot drills. Diameters of the holes

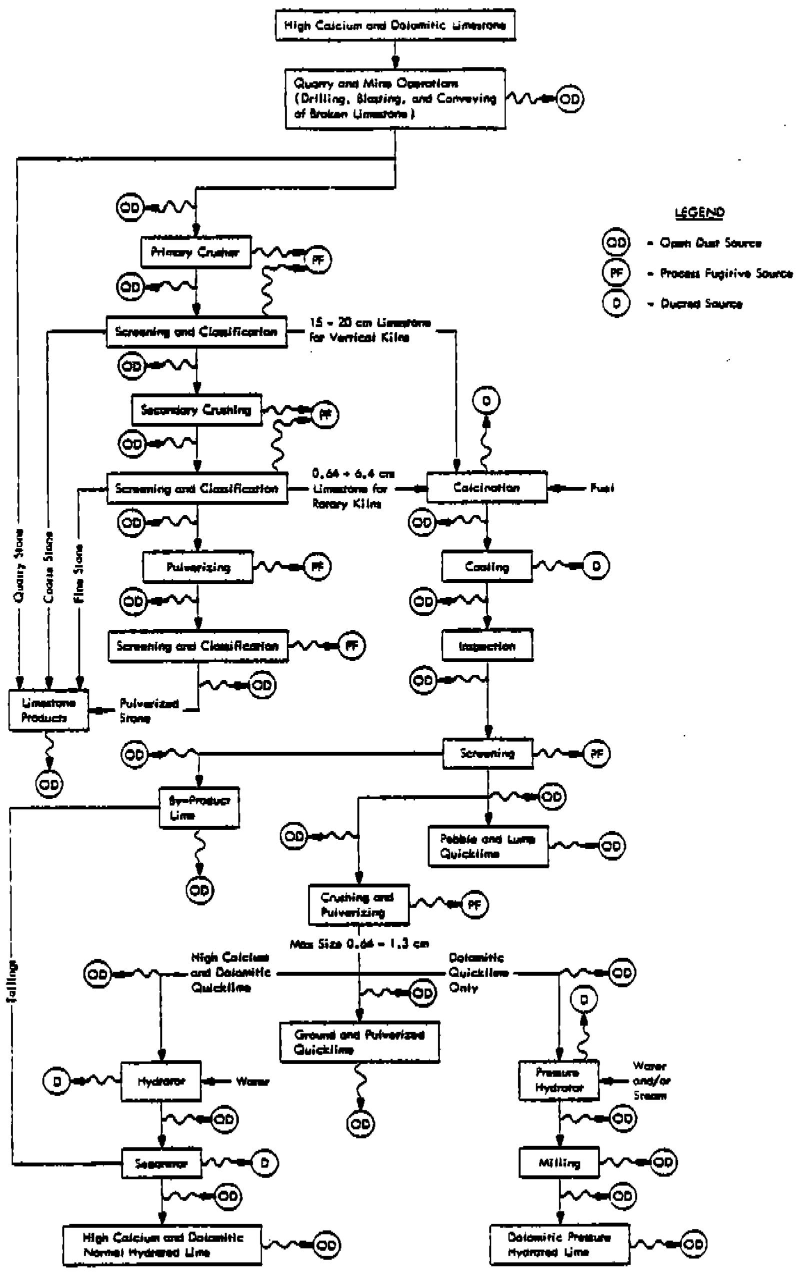

Figure 2-2. Simplified flow diagram for lime and limestone products.

vary from 5 to 25.4 cm (2 to 10 in.). Oversized boulders usually are reduced to manageable sizes following the blast.

Quarries that excavate soft stone, notably marl or chalk, do not drill or blast, but extract the stone with heavy-duty rippers and scrapers.[1] In the Midwest and Florida, lake marls and soft coralline limestone are dredged, in a process like strip-mining, forming canals.

Most underground limestone mines in the United States are relatively shallow room and pillar mines of 3 to 30 m (10 to 100 ft) depth.[1] However, some deep mines, reminiscent of coal operations, reach depths of 300 m (1,000 ft) with stope-mining techniques from a central vertical shaft. Because stone extracted from deep mines is too costly to compete at the marketplace it is generally mined for captive consumption (i.e., for making higher-priced products) such as lime and chemicals.

Loading of stone is done with power shovels almost exclusively. Generally, the size of the shovel is coordinated with the size of the primary crusher. The stone is loaded onto inclined rail-type cars for transport from the quarry proper to the primary crusher. Rugged rubber-wheeled off-highway trucks are very commonly employed.

The emissions associated with stone extraction consist of fugitive dust generated during drilling, blasting, crushing, and handling operations. Significant fugitive emissions are also created by vehicular traffic on unpaved and paved roads.

2.3.2 Stone Processing

2.3.2.1 Crushing and Sizing Operations--

This processing step involves the crushing, pulverizing or grinding, and sizing of the raw quarry or mine feedstock. Lime manufacture requires stone of definite size ranges depending on the type of kiln used. The greatest influence on lime quality is the size gradation of limestone used to feed the kilns. Narrow gradations such as 10 x 20 cm (4 x 8 in.), 2.5 x 5 cm (1 x 2 in.), 0.5 x 1 cm (0.2 x 0.4 in.), or narrower are very conducive to uniform calcination.

Preparation of crushed stone requires a series of crushing, screening, and classifying operations. Primary crushers may be either jaw or gyratory type. Reduction in the primary crusher is generally not greater than 6:1. Depending on rock hardness, roll crushers and hammer mills may also be used. In most cases, the primary crusher will be located at the quarry or mine.

Secondary crushing of stone to sizes 2.5 cm (1 in.) and under is achieved in cone crushers and high speed, flat-angle gyratory crushers. Sometimes hammer mills are employed on less abrasive stone. Depending upon demand, some of the crushed limestone may be sold as by-product incidental to the main calcining process. Some pulverizing is done to further reduce undersize stone that is generally unsuitable for feed to the kilns. The material from this operation is sold as by-product agricultural limestone. Occasionally, the stone may be dried in a rotary drier to facilitate better pulverizing.

Vibrating screens of various types are the most prevalent method of classifying all sizes of limestone. The type and size of machine and the frequency of vibration is determined by the size gradation of the stone to be screened. Many lime plants are able to reduce the impurities in their lime product by careful screening and selecting the stone for burning. It should be noted that the percentage of impurities in a quicklime is nearly double that in the original stone.[3]

Provisions are made in almost every plant to store very large quantities of processed or semiprocessed stone. This is necessary to balance fluctuating demand for lime products against the production and availability of raw material. Crushed stone is kept in large open stockpiles or surge piles. Material is usually conveyed to these piles by conveyor belt. A tunnel conveyor under the pile allows withdrawal for further processing in all types of weather. The most prevalent stone-conveying equipment is the rubber belt conveyor in conjunction with bucket elevators. Undersize material called spall is also stored in stockpiles.

To comply with stringent product specifications, some plants beneficiate the semiprocessed stone by removing clay and soil clinging to limestone. Several wet methods are used: washing; scrubbing; flotation; and heavy-media separations are used for removing silica (flint and quartz). Optical mineral sorters use compressed air to deflect stone particles deviating from a preset color standard; and handpicking from conveyor belts is still practiced by some plants.

The main source of ducted emissions in crushing and sizing operations is the rotary dryer. Emissions from rotary dryers consist of particulate matter as well as combustion-related pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOC). Various types of dust collectors are used to control particulate emissions from rotary dryers.

Process-related fugitive dust is generated during crushing, screening, pulverizing, and associated materials transfer operations. Open dust sources include conveyor transfer points, bucket elevators, truck loading operations, stone and spall stockpiles (including wind erosion), and vehicular traffic on unpaved roads.

2.3.2.2 Dredging and Washing of Sea Shells--

This process involves the use of sea-going suction dredges to "mine" oyster or clam shells found in beds or reefs located along sea coasts (particularly the Texas-Louisiana Gulf Coast) where no limestone deposits are found within miles of the coast. Sea shell beds may be classed as unconsolidated limestone deposits.

In practice, large suction pies on the dredge, equipped with rotary cutting heads revolving at 9 to 15 rpm, are dripped onto the reef. Large pumps pick up the dislodged shell and transport it to the top of the dredge for rough washing. The dredged up shells are rough-washed on board with fresh high pressure seawater to dislodge silica, silt, and mud. The washing step is facilitated using single- or two-stage screens or trommels. The rough washed shells are transported by a boom conveyor and stacked on barges alongside the dredge. Barges are moved by tugboat to the offloading dock some distance from the dredge. At the dock, shell is off-loaded using derrick clamshell buckets.

Sea shells unloaded from barges are given a fresh water wash to remove residual seawater and salts. For high purity commercial chemical lime, shell washing is mandatory. In some cases, the shell user must "scrub" the incoming material in order to remove encrustations of silica that would otherwise lower overall purity of the final lime product. Washing is done using rotary screens or trommels. These may be either single- or two-stage washer screens. Prior to feeding into the kilns, the shells go through a second screening process to separate out the fines. These fines are generated as a result of mechanical breakage during handling. Some of the washed and sized shell fines are sold for chicken grits and as agricultural limestone by-products.

Finally, the washed and screened shells are transported and dumped onto surge piles to await conveying to the rotary kilns. Loading and feeding is usually done with a combination of stocking conveyors, stockpile loaders, and inclined belt conveyors. Relative small amounts of fugitive dust is generated during these materials handling operations due to the generally wet nature of the material.

2.3.3 Calcination and Pulverization

2.3.3.1 Calcination--

During calcination, crushed limestone rock or sized shell is heated to a high temperature to convert the carbonate to oxide. Carbon dioxide is driven off as a by-product and may or may not be recovered for other uses. In the early stages of calcination, moisture and volatile organic matter are driven off. As the temperature of the limestone (or shell) rises, decomposition begins, releasing carbon dioxide. Rapid decomposition does not take place until a temperature of 700° to 800°C (1290° to 1470°F) is reached for dolomitic limestone and 830° to 930°C (1530° to 1700°F) for high-calcium raw materials.

Dead-burned dolomite (refractory grain) is the commercial name for refractory lime. This product, with few exceptions, is made in rotary kilns. It is a highly sintered form of dolomitic lime that has been calcined at temperatures up to 1635° to 1820°C (3000° to 3300°F). Usually 5 to 8% of iron oxide is added. The MgO component is converted to periclase and the entire product is rendered chemically less reactive than materials calcined at lower temperatures. The product is grayish-brown in color and is available in various granular sizes from about 1 cm (0.4 in.) to <20 mesh. Primary use of this material is for lining basic oxygen steel furnaces. Before shipment of this product, a light spray or asphaltic based oil is added to enhance stability of the product and reduce dust generation.

In the United States, four types of kilns are used for the calcining of lime: rotary kiln; vertical kiln; rotary hearth (Calcimatic) kiln; and fluidized bed kiln. Rotary kilns are predominant in the United States, primarily because of their high production rate. However, rotary kilns are limited to small size stones (between 0.6 and 6.3 cm). Vertical kilns burn lump size limestone between 7.6 and 30.5 cm (3 to 12 in.). The vertical kiln is the most widely used kiln in European and other countries. The rotary hearth or "calcimatic" type kiln is of recent development in lime kilns and has the distinct advantage of being able to accommodate a rather wide range of stone sizes, including relatively broad size distributions like 0.6 to 10.2 cm (0.25 to 4 in.). The fluidized bed kiln, resembling a large vertical kiln, utilizes a fine particulate kiln feed of 8 to 65 mesh. A brief description of each type of kiln is presented below.

In the United States, nearly 90% of commercial lime capacity and about 50% of captive lime is calcined in <u>rotary kilns</u>.[1] Rotary kilns achieve the highest production capacity of all kilns. The largest rotary kiln in operation in the United States is reportedly rated at 1,500 to 1,600 metric tons (1,650 to 1,760 short tons) per day.[1] The overall sizes of these kilns varies considerably, from 2.1 to 5.1 m (6.9 to 16.7 ft) in diameter and from 45 to 128 m (148 to 420 ft) in length. The exterior of the kiln is heavy steel boiler plate and the interior lining is composed of refractory brick. Since World War II, most rotary kilns have been equipped with heat-recuperative accessories such as kiln feed preheater and product cooler.[1] A diagram of a rotary kiln is found in Figure 2-3. Rotary kilns are normally installed at a 3 to 5 degree inclination on four or six foundation piers and revolve at 30 to 50 seconds per revolution. Limestone is fed into the elevated end of the kiln and is discharged as quicklime at the lower end. On some installations the quicklime is discharged into satellite cooling cylinders through which the input air to the kiln is fed. This acts to not only cool the quicklime, but also preheat the input air to the kiln. In other operations indirect heat exchangers are used in place of satellite coolers for preheating the combustion air to the kiln.

Most rotary kilns in the United States are fired with pulverized coal, but are also adaptable to gas and oil firing.[1] Only 10% of the kiln is filled with limestone/lime as the kiln feed tumbles gently through the kiln. Kiln feed ranges in size from 0.625 to 6.25 cm (0.25 to 2.5 in.), but multiple rotary-kiln plants use more restricted gradations of 0.625 to 1.88 (0.25 to 0.74 in.), and 1.88 to 3.75 cm (0.74 to 1.5 in.), etc.

At one time, the vertical kiln, or shaft kiln as it is sometimes called, was the most widely used kiln in the United States. Although many vertical kilns remain in operation, the total capacity of the vertical kiln has fallen well below that of the rotary kiln. Figure 2-4 is a schematic of a vertical lime kiln.

The vertical kiln can be described as an upright cylinder lined with refractory. The kiln is charged at the top with large lump-size limestone. All of these kilns have four imaginary zonal sections, as depicted in Figure 2-4. In the preheating zone, recirculated exhaust gases preheat the stone, preparatory to calcination in the zone below. The calcining zone is the calcination chamber where 95% of lime burning occurs. The lower portion of this zone is called the finishing zone where calcination is completed and

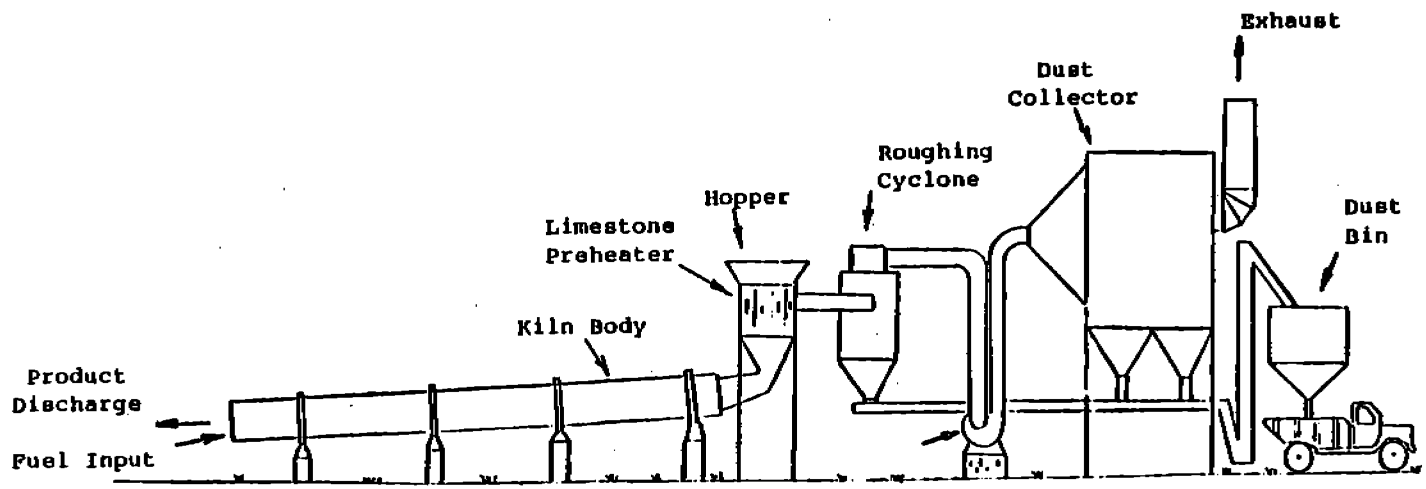

Figure 2-3. Schematic diagram of rotary kiln.[4]

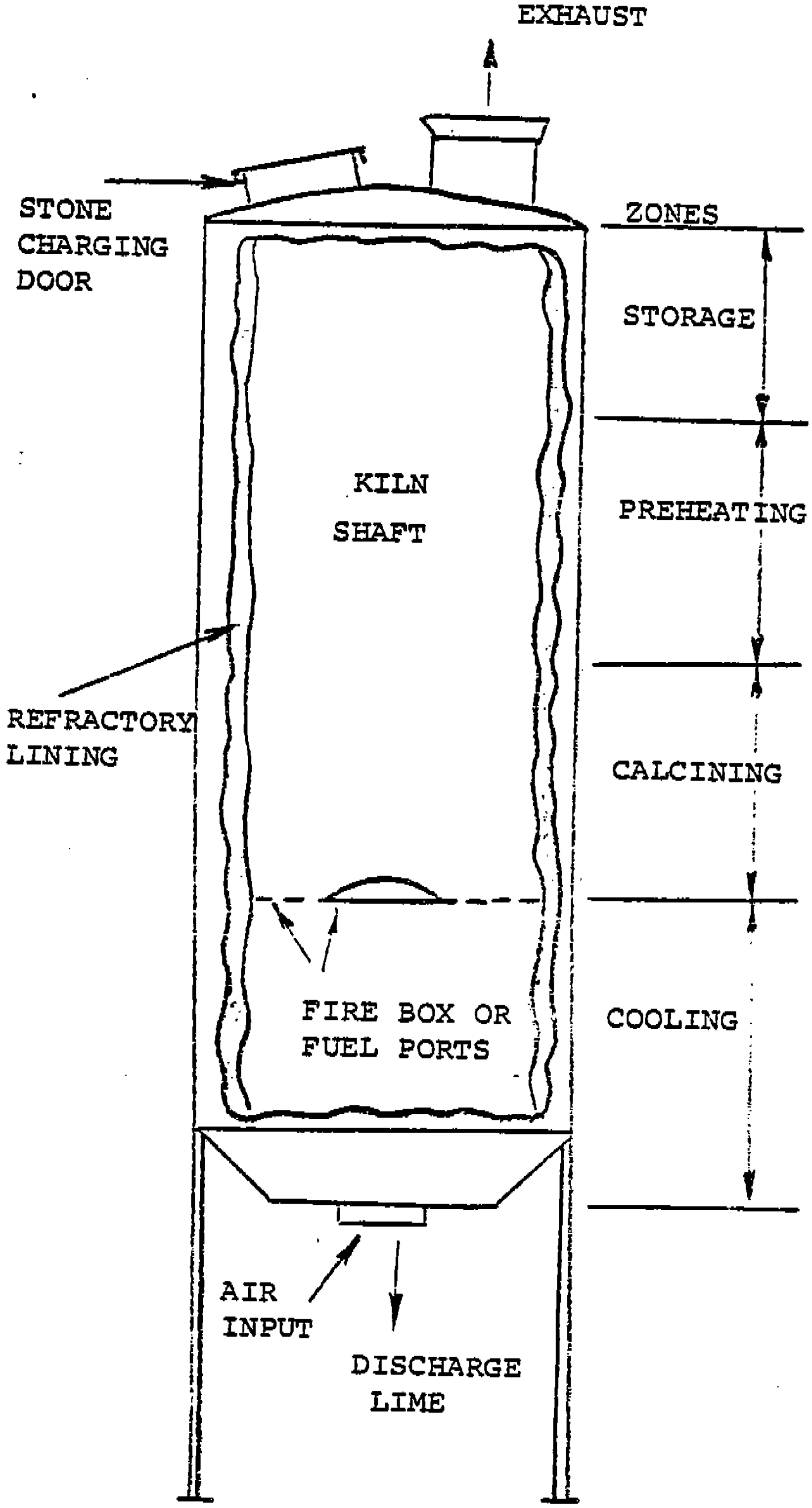

Figure 2-4. Schematic diagram of vertical kiln.[4]

where ports for firing are located. Cool air enters the cooling zone from the base of the kiln or discharge point and by natural, induced, or forced draft flows upward countercurrent to the lime descending through the kiln. The air cools the lime for discharge onto conveyors below, and the air recoups much heat from the red-hot lime as secondary combustion air for the calcining above.

Vertical kiln dimensions may vary from 2.4 to 7.6 m (8 to 25 ft) in diameter and from 10.7 to 30.5 m (35 to 100 ft) in height. Modern vertical kilns can produce as much as 600 to 800 metric tons (660 to 880 short tons) per day of lime. A primary advantage of vertical kilns over rotary kilns is the higher average fuel efficiency. The primary disadvantage of the vertical kiln is its relative low production rate as compared to the rotary or rotary hearth kiln.

The majority of vertical kilns have no dust collection equipment.[4] This is attributed to the relatively low dust production rates associated with such equipment.[4] It is thought that the low particulate emissions from vertical kilns are at least partially due to the fact that lump-size limestone is used as feed to the kiln (thus reducing the amount of fine particles available for resuspension) and the relatively slow movement of material through the kiln.

The rotary hearth or "calcimatic" kiln is a circular shaped device which incorporates a slowly revolving donut-shaped hearth. Limestone is distributed in a 2.5 to 15 cm (1 to 6 in.) deep layer on the rotating calcining zone with the finished lime scraped off about 350 degrees around the circle from the point where the feed is deposited onto the hearth. The heated gases from the calcining zone of the kiln are passed through the feed for preheat purposes, similar to that present in vertical kilns. In some cases, product cooling is conducted in an indirect heat exchanger where the burner combustion air is preheated thus increasing fuel economy.

The rotary hearth kiln combines the advantages of the rotary kiln and the vertical kiln in that a high production rate can be achieved with low dust emissions. The rotary hearth kiln also can accommodate the feed size range of both the rotary and vertical kilns. The low dust emission of the rotary hearth kiln is attributed to the fact that the limestone is held in a stationary position relative to the kiln during calcining. Particulate emissions from rotary hearth kilns are often effectively controlled through the use of low efficiency dust collectors.

The last type of kiln to be discussed is the fluidized bed kiln. In this process, finely divided limestone is brought into direct contact with hot combustion air in a turbulent zone, usually above a perforated grate. The stone is physically agitated by the turbulent airstream and generous quantities of dust are carried out of the reaction zone by the combustion air. Very high production rates and rapid response to process changes are characteristic of the fluidized bed process. Sophisticated dust collection equipment (such as venturi scrubbers, fabric filters, or electrostatic precipitators) are necessary not only for emission control purposes but also for process economics.

Calcining kilns are the largest single source of ducted emissions found in lime plants. Kiln emissions consist of particulate matter and VOC from calcination as well as other combustion-related pollutants. A comparison of the four types of kilns in terms of particulate emissions reveals the fluidized bed kiln to have the highest uncontrolled dust output. This is primarily due to the very small feed size combined with the high airflow through the kiln.

The rotary kiln is second to the fluidized bed kiln in uncontrolled particulate emissions. This is attributed to the small size of the feed (fine particle resuspension) caused by tumbling of the material through the kiln. The rotary hearth (or "calcimatic") ranks third in dust production, primarily because of the larger size of the kiln feed combined with the fact that the limestone remains stationary during calcining. The vertical kiln has the lowest dust emission during operation. This is attributed to the large lump-sized feed and the relatively slow movement of the feed material through the kiln. Coolers can also be sources of particulate emissions if not recycled to the kiln.

2.3.3.2 Pulverization and Shipping--

Regardless of the type of kiln employed, quicklime is conveyed by belt conveyor to screens where the fines and undersized particles are removed. Most quicklime is shipped in bulk, with covered hopper-bottom railcars being preferred. Less than 1% of the lime produced is packed in bags.

Lime is available in various mesh sizes, varying all the way from fine pulverized grades to lumps. In general, lumps from vertical kilns will range from 6 to 25 cm (2.4 to 10 in.) in diameter. Pebble lime (usually from rotary kilns) ranges from 0.6 to 6.0 cm (0.25 to 2.5 in.), with the high end sometimes obtained from crushed lumps (from vertical kilns). Table 2-6 provides information on the physical form and size of various types of quicklime.[1]

TABLE 2-6. PHYSICAL FORMS AND SIZES OF QUICKLIME[1]

Physical form	Size range	Derivation
Lump	63-255 mm	Vertical kiln
Pebble	6.3-63 mm	Rotary, special kilns; crushed lump
Ground	100% < 2.38 mm (<8 mesh); 40-60% < 1.49 mm (<10 mesh)	Fluidized bed kiln; screening, grinding
Pulverized	100% < 0.84 mm (<20 mesh); 80-90% < 1.49 mm (<10 mesh)	Pulverizing; screened dust
Pellets (briquettes)	16.4-55.7 cm^3 (13.4 $in.^3$)	Screened fines and dust
Dead-burned dolomite	0.84-9.5 mm (20-2 mesh)	Iron-stabilized, dead-burned dolomite granules--screened

Air-swept hammer mills are commonly used for grinding, although impact breakers, small gyratory crushers, and cone mills are also used. Screening steps similar to those in stone processing are also applied to some lime milling operations.

If hydrated lime is to be made, grinding equipment is employed to pulverize and reduce the lump or pebble quicklime to 0.5 to 1.24 cm (0.2 to 0.5 in.) or smaller. Also, waste quicklime fines that are screened off at the kiln discharge are also normally used as feed to the hydration process.

The fugitive emissions associated with pulverization and shipping of quicklime are similar to those found in stone processing. Sources include kiln discharge, conveyor transfer points, elevators, crushing/pulverizing operations, railcar load-in, bagging, etc.

2.3.4 Hydration

Although the major tonnage of lime is sold as quicklime, there is still a substantial production of hydrated lime. This product is made in the form of a fluffy, micron-size, dry white powder.

Hydration consists of slowly adding water to a crushed or ground quicklime in a premixing chamber or a vessel known as a hydrator, both of which mix and agitate the lime and water. The amount of water to be added is critical. If too much water is added, it will be impossible (or require costly drying) to produce the desired dry form. If too little water is added, incomplete hydration will cause degraded quality, chemical instability, and structural unsoundness.[1]

In the United States, three types of hydrators are predominant in the lime industry: the Schaffer hydrator; the Kritzer hydrator; and the autoclave or pressure hydrator. The pressure hydrator, operating under a pressure of from 276 to 690 kPa (40 to 100 psig) is often employed when hydrating a dolomitic quicklime.[1]

Hydrator emissions are normally controlled by the use of either water sprays in the hydrator stack or by wet scrubbers. In either case, the dust particles are entrapped by sprays and the resulting slurry (or milk of lime) is piped back to the hydrator's premixer as part of the slaking water. Besides preventing lime losses, the need for treatment of the water effluent is averted. Virtually all efficient hydrators have either water sprays or wet scrubbers integrally installed. Most of the exhaust from a hydrator is steam generated by the heat of hydration.[4]

Normally, hydrated dolomitic lime consists of calcium hydroxide and magnesium oxide with little if any magnesium hydroxide. However, dolomitic lime can be completely hydrated in an autoclave under pressure. Table 2-7 provides typical product analyses for commercial hydrated limes.[3]

TABLE 2-7. TYPICAL PRODUCT ANALYSES OF COMMERCIAL HYDRATED LIMES[3]

Component	High-calcium hydrated limes, % range	Highly hydrated dolomitic lime, % range
CaO	71 - 74	41 - 45
MgO	0.5 - 2	25 - 30
H_2O	24 - 25	27 - 28
CO_2	0.3 - 0.7	0.3 - 0.7
SiO_2	0.2 - 0.5	0.2 - 0.5
R_2O_3*	0.1 - 0.3	0.1 - 0.3

* Heavy metal oxides.

Closed circuit conveyors are used for transporting the semiprocessed hydrate from the hydrator to the finishing part of the process. This is done to prevent recarbonation of the hydrated lime. Usually a system of horizontal screw conveyors and bucket elevators are employed.

Any uncalcined lime, overburned material, or silica in the hydrated products is removed in an air separator after the hydration step is completed. Centrifugal air separators are universally employed in the final milling and classification of the product. Finished dry hydrate product is transported to product silos and from there to bagging machines.

Some hydration lime is also carried out with great excess of water so that a slurry of "milk of lime" solution is produced instead of a dry powder. This process is usually called slaking. Slaking equipment is usually located at the plant site of the user. Only in cases where the lime producer has a captive use for slaked lime will a slaker be employed at the lime plant proper.

The major sources of ducted emissions are the hydrator, classifier, and grinding mill air separators. Fugitive emissions are generated during materials handling and conveying operations as well as during product storage and bagging. Slaker processes do not generate any significant amount of air pollutants due to the high moisture content of the material.

A summary of the processes, sources, and pollutants generated in lime manufacturing plants is provided in Table 2-8.

2.4 CONTROL TECHNOLOGY

2.4.1 Ducted and Process Fugitive Sources

Particulates exhausted from lime calcining kilns are a mixture of limestone dust and burnt lime. These two compounds are quite different in their ability to be collected. Limestone dust in nonreactive and can be collected, transported, wet or dry, with no basic changes taking place. Burnt lime, however, undergoes chemical reaction with carbon dioxide as it slowly reverts back to limestone. By water addition, caking can occur, which often causes problems when wet scrubbing is used for controlling such emissions.[4]

TABLE 2-8. SUMMARY OF EMISSION SOURCES IN LIME MANUFACTURING PLANTS

Basic process	Source description	Type of emissions[a]	Pollutants generated[b]
Stone extraction	Overburden removal and disposal	OD	PM
	Drilling and blasting	OD	PM
	Loading	OD	PM
	Materials handling	OD	PM
Crushing and sizing	Primary crushing	PF	PM
	Screening/classifying	PF	PM
	Secondary crushing	PF	PM
	Rotary dryer	D	PM, SO_2, NO_x, CO, VOC
	Pulverizing	PF	PM
	Conveying to storage piles	OD	PM
	Truck loading	OD	PM
	Reclaiming and conveying to kiln	OD	PM
Dredging and washing of sea shells	Stockpiling	OD	PM
	Reclaiming and conveying to kiln	OD	PM
Calcination	Lime kilns	D	PM, SO_2, NO_x, CO, VOC
	Coolers	D	PM
Pulverization and shipping	Conveying to screens (including kiln discharge)	OD	PM
	Screening	PF	PM
	Conveying to railcars	OD	PM
	Railcar load-in	OD	PM
	Bagging	OD	PM
	Pulverizing	PF	PM
Hydration	Conveying to hydrator	OD	PM
	Hydrator	D	PM
	Conveying to finish process	OD	PM
	Mill air separator	D	PM
	Conveying to storage silos	OD	PM
	Bagging	OD	PM
Paved and unpaved roads	Vehicular traffic	OD	PM
Storage piles and exposed areas	Wind erosion	OD	PM

[a] OD - Open dust source
PF - Process fugitive source
D - Ducted emission source

[b] PM - Particulate matter
SO_2 - Sulfur dioxide
NO_x - Nitrogen oxides
CO - Carbon monoxide
VOC - Volatile organic compounds

As stated above, the ranking of lime kilns in terms of highest average dust emission to lowest average dust emission is[4]:

1. Fluidized bed kiln.

2. Rotary kiln.

3. Rotating hearth (Calcimatic) kiln.

4. Vertical kiln.

Five types of emission control are found to be predominant in controlling dust emissions from lime kilns. These control systems are: fabric filter (baghouse) collectors; electrostatic precipitators; high energy wet scrubbers; low energy wet scrubbers; cyclone or "multiclone" collectors; and gravel-bed filters. There are a number of good references which describe the theory, operation, and applicability of the control devices listed above and thus such will not be discussed here.[5,6]

The type of dust collector used in a particular application will be on the type of kiln and whether it is required to meet applicable New Source Performance Standards (NSPS) or whether only state and local regulations apply. Table 2-9 summarizes the control equipment used on 84 rotary kilns and five rotary hearth kilns in a January 1974, survey of lime plants in the states of Ohio, Pennsylvania, Texas, Missouri, and Alabama.[4] In the five rotary hearth installations, three are controlled by high energy scrubbers, one is controlled with a baghouse collector, and one is controlled with a multiclone type collector. All five rotary hearth kilns are operating within respective state regulations.[4] There is usually no supplemental equipment installed on lime kilns for the control of gaseous pollutants such as SO_2 and NO_x. However, it should be noted that some control of SO_2 is inherent in the operation of most dust collection equipment due to the alkaline nature of the particles collected.

TABLE 2-9. PARTICULATE CONTROL EQUIPMENT USED IN 1974 ON 89 LIME KILNS[4]

Control device	No. in operation	%
Cyclone	9	10.1
Baghouse	18	20.2
Electrostatic precipitator	6	6.8
High energy scrubber	33	37.1
Low energy scrubber	5	5.6
None	18	20.2
Total	89	100.0

As pointed out above, hydrator emissions are most effectively controlled by the use of water sprays or wet scrubbers. In either method, the water effluent from the gas cleaning device is supplied to the hydrator's premixer as part of the slaking water. In this manner, all hydrated lime losses are generally averted along with the need for secondary treatment of the scrubber effluent water.

Normally associated with lime hydration are milling and bagging processes. Raymond mills are often used in the milling of hydrated lime to enhance the fineness of the powder and upgrade its chemical purity. Fabric filters with cyclonic precleaners are often employed on these milling processes, bagging processes, and on associated transfer points in the system.

For the remainder of the sources of process fugitive emissions such as crushers, vibratory screens, pulverizers, etc., a wide variety of control techniques can be applied. These include: capture and collection systems using various types of dust collectors; enclosures (full or partial, evacuated or nonevacuated); wet suppression (with and without surfactants, foam, etc.); and process modifications. The type of control used will vary from plant to plant.

2.4.2 Open Dust Sources

The emissions from open dust sources in lime plants can be controlled by a wide variety of different methods. Conveyor transfer points and bucket elevators are usually controlled either with enclosures evacuated to a dust collector or by wet suppression using plain water, water with a surfactant, or micronized foam. Truck and railcar loading operations can likewise be controlled by capture and collection systems or, in some cases, wet suppression depending on whether raw material or finished product is being loaded.

Emissions from drilling operations during stone extraction are usually controlled with a self-contained ventilation system equipped with a small fabric filter. Loading of limestone by shovels can be controlled by wet suppression or potentially by portable wind screens. Emissions from truck traffic on unpaved roads can be mitigated by watering, chemicals, or by paving. For paved roads, sweeping is really the only means for controlling such emissions. Storage pile load-in/load-out and wind erosion emissions are generally controlled by wet suppression. The exact control strategy employed will vary depending on local regulations, proximity to receptors, and other related factors.

REFERENCES FOR SECTION 2.0

1. Kirk-Othmer, Encyclopedia of Chemical Technology, Volume 14, Third Edition, John Wiley and Sons, NY, 1981.

2. U. S. Bureau of Mines, Minerals Yearbook 1980, Volume I, U. S. Government Printing Office, Washington, D.C., 1981.

3. Doumas, A. C., et al., Industrial Process Profiles for Environmental Use, Chapter 18, The Lime Industry, EPA-600/2-77-023r (NTIS PB 281485), U. S. Environmental Protection Agency, Cincinnati, OH, February 1977.

4. Screening Study for Emissions Characterization from Lime Manufacture, EPA Contract No. 68-02-0299, Vulcan-Cincinnati, Cincinnati, OH, August 1974.

5. Control Techniques for Particulate Emissions from Stationary Sources-Volume I, EPA-450/3-81-005a, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1982.

6. Control Techniques for Particulate Emissions from Stationary Sources-Volume II, EPA-450/3-81-005b, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1982.

SECTION 3.0

GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

The first step of this investigation was an extensive search of the available literature relating to the particulate emissions associated with lime manufacturing. This search included: data collected under the current inhalable particulate emission characterization program; information contained in the computerized Fine Particle Emission Inventory System (FPEIS); source test reports and background documents for Section 8.15 of AP-42 located in the files of the EPA's Office of Air Quality Planning and Standards (OAQPS); test reports supplied by the National Lime Association; and MRI's own files (including Kansas City and North Carolina Offices). The search was thorough but not exhaustive. It is expected that certain additional information may also exist, but limitations in funding precluded further searching.

To reduce the large amount of literature collected to a final group of references pertinent to this report, the following general criteria were used:

1. Source testing must be a part of the referenced study. Some reports reiterate information from previous studies and thus were not considered.

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

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to the criteria stated above. This set of documents was further analyzed to derive candidate emission factors for particulate matter based on particle size. Due to limitations in funding, no attempt was made to obtain further information on a particular test series above what was included in the original report. Such an effort was beyond the scope of the current program.

3.2 EMISSION DATA QUALITY RATING SYSTEM

As part of MRI's analysis of the available data, the final set of reference documents were evaluated as to the quantity and quality of the information contained in them. The following data were always excluded from consideration.[1]

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

2. Test series representing incompatible test methods.

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.

5. Test series in which it is not clear whether the emissions measured were controlled or uncontrolled.

If there was no reason to exclude a particular data set, each was assigned a rating as to its quality. The rating system used was that specified by the OAQPS for the preparation of AP-42 Sections.[1] The data were rated as follows:

A - Multiple tests performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily have to conform to the methodology specified in either the IP protocol documents, or by EPA reference test methods, although such were certainly used as a guide.

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

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

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

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

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

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

3. Sampling and process data. Adequate sampling and process data are documented in the report. Many variations can occur without warning during testing and sometimes without being noticed. Such variations can induce wide deviations in sampling results. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and were given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those specified by EPA (if any) 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.

As a general rule, any tests conducted strictly for the purpose of developing NSPS for a particular source category were not rated higher than B. This is due to the fact that these tests represent facilities which are considered as especially well-maintained, operated and controlled plants and thus may not be truly representative of the industry as a whole.

3.3 PARTICLE SIZE DETERMINATION

There is no one method which is universally accepted for the determination of particle size. A number of different techniques can be used which measure the size of particles according to their basic physical properties. Since there is no "standard" method for particle size analysis, a certain degree of subjective evaluation was used to determine if a test series was performed using a sound methodology for particle sizing. The following is a brief explanation of how particle size is defined and the various methods available for particle size measurement.

3.3.1 Particle Size Definitions

Examination of particles with the aid of an optical or electron microscope involves the physical measurement of a linear dimension of a particle. The measured "particle size" is related to the particle perimeter or to the particle projected area diameter. Particle size measurement in this manner does not account for variation in particle density or shape.[2]

All laws describing the properties of aerosols can be expressed most simply for particles of spherical shape. To accommodate nonspherical particles it is customary to define a "coefficient of sphericity" which is the ratio of the surface area of a sphere with the same volume as the given particle to the surface area of the particle.[2] An estimate of particle volume can be obtained from microscopic sizing, and by assuming a density, one can obtain an estimate of particle weight.

Because of large variations in particle density and the aggregated nature of atmospheric particles, it is useful to define other quantities as a measure of particle size based on their aerodynamic behavior. The Stoke's diameter is defined as the diameter of a sphere having the same settling velocity as the particle and a density equal to that of the bulk material from which the particle was formed, or:[3]

$$D_s = \sqrt{\frac{18\ V_s\ \eta}{g\ \rho\ C(D_s)}} \quad \text{for Re} \leq 0.5 \tag{3-1}$$

where:

D_s = Stoke's diameter (cm)

V_s = terminal settling velocity of a particle in free fall (cm/sec)

η = viscosity of the fluid (gm/cm·sec)

g = gravitational constant (980.665 cm/sec^2)

ρ = density of the particle (gm/cm^3)

$C(D_s)$ = Cunningham's slip correction factor for spherical particles of diameter D_s (dimensionless)

$$\cong 1 + \frac{2A\lambda}{D_s} \tag{3-2}$$

with:

$$A = \alpha + \beta\ \exp(-\gamma\ D_s/2\lambda) \tag{3-3}$$

α = empirical constant (dimensionless) $\cong$ 1.23 - 1.246
β = empirical constant (dimensionless) $\cong$ 0.41 - 0.45
γ = empirical constant (dimensionless) $\cong$ 0.88 - 1.08
λ = mean free path of the fluid at stated conditions (cm)

$$\cong \lambda_o\ (\eta/\eta_o)\ (T/T_o)^{0.5}\ (P_o/P) \qquad (3\text{-}4)$$

λ_o = mean free path at reference conditions (cm)
η = gas viscosity at stated conditions (gm/cm·sec)
η_o = gas viscosity at reference conditions (gm/cm·sec)
T = absolute temperature (°K)
T_o = reference temperature = 296.16°K
P = absolute pressure (kPa)
P_o = reference pressure = 101.3 kPa
Re = Reynold's number (dimensionless)

For particles greater than a few microns in diameter, a less rigorous form of Equation 3-1 can be used with reasonable accuracy according to the relationship:[4,5]

$$D_s = \sqrt{\frac{18\ \eta\ V_s}{(\rho-\rho')g}} \qquad Re \leq 0.05 \qquad (3\text{-}5)$$

where:

ρ, g, D_s, and η are as defined above; and

ρ' = density of air at the appropriate temperature and pressure (gm/cm^3)

Since dispersion and condensation aerosols are usually formed from many materials of different densities, it is more useful to define another parameter called the aerodynamic diameter, which is the diameter of a sphere having the same falling velocity as the particle and a density equal to 1 g/cm^3.[2,3] The classical aerodynamic diameter differs from the Stoke's diameter only by virtue of difference in density, assumed equal to unity, and the slip correction factor, which, by convention, is calculated for the aerodynamic equivalent diameter. From Equation 3-1:[3]

$$D_{Ae} = \sqrt{\frac{18\eta V_s}{gC(D_{Ae})}} \qquad (3\text{-}6)$$

where D_{Ae} = "classical" aerodynamic equivalent diameter (cm), with η, V_s, g, C as previously defined in Equation 3-1.

Equations required for interconversion between Stoke's and aerodynamic diameters are presented in Table 3-1.[3]

TABLE 3-1. EQUATIONS USED FOR PARTICLE SIZE CONVERSIONS[3]

Diameter definition (given)	Conversion equation[a]: Stoke's diameter (D_s)	Conversion equation[a]: Classical aerodynamic equivalent diameter (D_{Ae})
Stoke's diameter	1.0	$D_{Ae} = D_s \left[\frac{\rho C(D_s)}{C(D_{Ae})}\right]^{1/2}$
Classical aerodynamic diameter (D_{Ae})	$D_s = D_{Ae} \left[\frac{C(D_{Ae})}{\rho C(D_s)}\right]^{1/2}$	1.0

[a] Notation: D_s = Stoke's diameter (μm)
D_{Ae} = Classical aerodynamic equivalent diameter (μm)
ρ = Particle density (g/cm³)
$C(D_s)$, $C(D_{Ae})$, = Slip correction factors (dimensionless)--see Equations 3-2, 3-3, and 3-4.

3.3.2 Particle Size Measurement

As stated previously above, particle size is determined by measuring certain physical properties of the particulate being analyzed, such as its inertial, light scattering, sedimentation, diffusional, and electrical characteristics. The size distribution of an aerosol can be determined either directly at the source (i.e., stack or vent) or indirectly by the collection of a bulk sample of the material for subsequent analysis in the laboratory. In either case, the instrument(s) utilized to make such a determination can be manual or automated depending on the individual technique.

The five basic methods for the direct measurement of particle size are:

1. Aerodynamic separators (cascade impactors, cyclones, elutriators, etc.)

2. Light-scattering optical particle counters

3. Electrical mobility analyzers

4. Condensation nuclei counters

5. Diffusion batteries

All of the above are extractive methods, with the exception of certain aerodynamic separators.

Indirect methods for the determination of particle size include:

1. Sieving (wet, dry, sonic)

2. Sedimentation

3. Centrifugation (inertial separation)

4. Microscopy (optical and electron)

5. Others (acoustic, thermal, spectrothermal emission)

Table 3-2 provides a guide as to the various methods for the determination of particle size based on certain physical properties of the particulate and notes the size range in which each is generally applicable.[6]

In most respects instruments that fractionate an aerosol on the basis of the aerodynamic properties of its components probably give the best practical assessment of size. Once flow conditions have been selected for the device, the terminal settling velocities of the particles collected in each stage or part of the instrument can be determined, even though particle specific gravity and shape factor are unknown.[3] Unless the particle shapes are extremely irregular, the details of precise geometric form can be bypassed and the likelihood of the particle's capture by a dust-collecting system can still be determined. Because the correct assessment of particle size properties is essential for the development of appropriate emission factors, an assessment by aerodynamic techniques was emphasized in reviewing and rating the individual data sets for sound methodology.

Examples of aerodynamic particle sizing instruments are centrifuges, cyclones, cascade impactors, and elutriators. Each of these instruments employs the unique relationship between a particle's diameter and mobility in gas or air to collect and classify the particles by size. For pollution studies, cyclones and impactors (primarily the latter) are more useful because they are rugged and compact enough for <u>in situ</u> sampling. <u>In situ</u> sampling is generally preferred because the measured size distribution may be distorted if a probe is used for sample extraction. In the following two subsections, methods of using impactors and cyclones are discussed.

3.3.2.1 Cascade Impactors--

Cascade impactors used for the determination of particle size in process streams consist of a series of plates or stages containing either small holes or slits with the size of the openings decreasing from one plate to the next. In each stage of an impactor, the gas stream passes through the orifice or slit to form a jet that is directed toward an impaction plate. For each stage there is a characteristic particle diameter that has a 50%

TABLE 3-2. GUIDE TO PARTICLE SIZE MEASUREMENT[6]

Method	Diameter of applicability (μm)
Optical	
Light imaging	0.5+
Electron imaging	0.001-15
Light scanning	1+
Electron scanning	0.1+
Direct photography	5+
Laser holography	3+
Sieving	2+
Light scattering	
Right angle	0.5+
Forward	0.3-10
Polarization	0.3-3
With condensation	0.01-0.1
Laser scan	5+
Electrical	
Current alteration	0.5+
Ion counting, unit charge	0.01-0.1
Ion counting, corona charging	0.015-1.2
Impaction	0.5+
Centrifugation	0.1+
Diffusion battery	0.001-0.5
Acoustical	
Orifice passage	15+
Sinusoidal vibration	1+
Thermal	0.1-1
Spectrothermal emission	0.1+

probability of impaction. This characteristic diameter is called the cut-point (D_{50}) of the stage. Typically, commercial instruments have six to eight impaction stages with a back-up filter to collect those particles which are either too small to be collected by the last stage or which are reentrained off the various impaction surfaces by the moving gas stream.[7]

The particle collection efficiency of a particular impactor jet-plate combination is determined by properties of the aerosol such as the particle shape and density, but the viscosity of the gas, and by the design of the impactor stage. There is also a slight dependence on the type of collection surface used (glass fiber, grease, metal, etc.). Reentrainment, or particle bounce, is a significant problem with cascade impactors especially in the case of high particulate loadings. This problem can be partially solved by using a preseparation device ahead of the impactor to reduce the overall loading of coarse particles.

3.3.2.2 Cyclone Separators--

Traditionally, cyclones have been used as a preseparator ahead of a cascade impactor to remove the larger particles. These cyclones are of the standard reverse-flow design whereby the aerosol sample enters the cyclone through a tangential inlet and forms a vortex flow pattern. Particles move outward toward the cyclone wall with a velocity that is determined by the geometry and flow rate in the cyclone and by their size. Large particles reach the wall and are collected.

A series of cyclones with progressively decreasing cut-points can be used also instead of impactors to obtain particle size distributions. The advantages are that larger samples are acquired, particle bounce is not a problem, and no substrates are required. Also, longer sampling times are possible with cyclones, which can be an advantage at very dusty streams, but a disadvantage at relatively clean streams. One such series cyclone system was developed by an EPA contractor specifically for the IP program.

3.4 PARTICLE SIZE DATA ANALYSIS METHODOLOGY

The particulate emission information contained in the various primary reference documents was reduced to a common format using a family of computer programs developed especially for this purpose (as shown in Table 3-3). These programs are fundamentally BASIC translations of the FORTRAN program SPLIN2 developed by Southern Research Institute.[8] The particular version translated is one that MRI modified earlier to operate utilizing as few as three data points. Additional changes were made to produce emission factors as functions of the aerodynamic particle diameter.

As mentioned above, SPLIN2 is the central portion of the program which uses the so-called "spline" fits. Spline fits result in cumulative mass size distributions very similar to those which would be drawn using a French curve and fully logarithmic graph paper. In effect, the logarithm of cumulative mass is plotted as a function of the logarithm of the particle size, and a smooth curve with a continuous, nonnegative derivative is drawn.

The process by which this smooth cumulative distribution is constructed involves passing an interpolation parabola through three measured data points at a time. The parabola is then used to interpolate additional points between measured values. When the set of interpolated points are added to the original set of data, a more satisfactory fit is obtained than would be the case using only the measured data.

The primary addition to the spline fitting procedure is the determination of size-specific emission factors once the size distribution is obtained by a spline fit. The user is prompted to input process and emission rate data. The program determines a total particulate emission factor by:

$$E_{TP} = \frac{e_{TP}}{R} \qquad (3\text{-}7)$$

TABLE 3-3. COMPARISON OF COMPUTER PROGRAMS

Fitted size distribution	JSKPRG Spline	JSKRAW Spline
Input requirements:		
particle size data	Cumulative mass fractions; particle density	Largest particle diameter; incremental mass fractions; particle density
process data	Process and emission rates - or - emission factor	Process and emission rates - or - emission factor
Output:	------------ Size-specific emission factors (English and metric units) for selected aerodynamic particle diameters	------------

where: E_{TP} = total particulate emission factor (lb/ton)

e_{TP} = total particulate emission rate (lb/hr)

R = process weight rate (tons of lime produced/hr)

Emission factors for each particle size range are then obtained by multiplying E_{TP} by the mass fraction associated with that range. The programs automatically convert the size-specific emission factors obtained from English units (lb/ton) to the appropriate metric units (kg/metric ton), which are tabulated as a part of the output format (1 kg/metric ton = 1 kg/10^6 g = 1 kg/Mg). As an additional function, each program has the capability of converting from Stoke's diameter to aerodynamic diameter using the appropriate density correction (Table 3-1).

Most of the programs also require that a largest particle diameter be provided to complete the size distribution. A maximum size of 200 µmA (aerodynamic diameter) was assumed unless other data were available. This value was selected since this is the largest particle size which might be expected based on the limited data contained in the literature. A complete listing of each program is provided in Appendix A with sample outputs shown in Figures 3-1 and 3-2.

3.5 EMISSION FACTOR QUALITY RATING SYSTEM

The quality of the emission factors developed from analysis of the test data was rated utilizing the following general criteria:[1]

- 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 to minimize variability within the source category population.

---

* Source category: A category in the emission factor table for which an emission factor has been calculated (generally a single process).

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: EXAMPLE OUTPUT OF "JSKPRG"

INPUT DATA: PROCESS WEIGHT RATE = 100 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 100 LB/HR
PARTICLE DENSITY = 2.44 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
10	15
20	25
30	34
50	50

OUTPUT DATA: TP EMISSION FACTOR = 1 LB/T (.5 KG/MT)

		EMISSION FACTOR	
CUT (umA)	CUM. % < CUT	(LB/T)	(KG/MT)
.625	1.78801	.0178801	8.94006E-03
1	2.3787	.023787	.0118935
1.25	2.73215	.0273215	.0136607
2.5	4.25364	.0425364	.0212682
5	6.74744	.0674744	.0337372
10	10.9053	.109053	.0545267
15	14.567	.14567	.0728348
20	17.9582	.179582	.0897908

END OF TEST SERIES

Figure 3-1. Example output of "JSKPRG."

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: EXAMPLE OUTPUT OF "JSKRAW"

INPUT DATA: PROCESS WEIGHT RATE = 100 TONS PROD. /HR
TOTAL PARTICULATE EMISSION RATE = 100 LB/HR
PARTICLE DENSITY = 2.44 G/CC

MEASURED PARTICLE SIZE DISTRIBUTION

CUT (um)	RAW % < CUT	CUM. % < CUT
10	15	15
20	10	25
30	9	34
50	16	50
74	50	100

OUTPUT DATA: TP EMISSION FACTOR = 1 LB/T (.5 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	1.78804	.0178804	8.94021E-03
1	2.37873	.0237873	.0118937
1.25	2.73218	.0273218	.0136609
2.5	4.25366	.0425366	.0212683
5	6.74745	.0674745	.0337373
10	10.9053	.109053	.0545267
15	14.567	.14567	.0728348
20	17.9581	.179581	.0897907

END OF TEST SERIES

Figure 3-2. Example output of "JSKRAW."

- 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. As in the A-rating, the source category is specific enough to minimize variability within the source category population.

- 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. As in the A-rating, the source category is specific enough to minimize variability within the source category population.

- 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 footnoted 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 footnoted.

The use of the above criteria is somewhat subjective depending to a large extent on the individual reviewer. Details of how each candidate emission factor was rated are provided in Section 4.0.

REFERENCES FOR SECTION 3.0

1. Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections, U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1980.

2. Calvert, S., et al., Wet Scrubber Systems Study, Volume I: Scrubber Handbook, EPA-R2-72-118a (NTIS PB 213016), U.S. Environmental Protection Agency, Research Triangle Park, NC, August 1972.

3. Galeski, J.B., Particle Size Definitions for Particulate Data Analysis, EPA-600/7-77-129 (NTIS PB 276470), U.S. Environmental Protection Agency, Research Triangle Park, NC, November 1977.

4. Sheehy, J. P., et al., Handbook of Air Pollution, 999-AP-44 (NTIS PB 190247), U.S. Department of Health, Education, and Welfare, Durham, NC, 1968.

5. Green, H. L., and W. R. Lane, Particulate Clouds: Dusts, Smokes and Mists, E. F. N. Spon, Ltd., London, 1964.

6. Dennis, R., Handbook on Aerosols, TID-26608, Energy Research and Development Administration, Washington, D.C., September 1978.

7. Smith, W. B., et al., Technical Manual: A Survey of Equipment and Methods for Particulate Sampling in Industrial Process Streams, EPA-600/7-78-043 (NTIS PB 282501), U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

8. Johnson, J. W., et al., A Computer-Based Cascade Impactor Data Reduction System, EPA-600/7-78-042 (NTIS PB 285433), U. S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

SECTION 4.0

PARTICULATE EMISSION FACTOR DEVELOPMENT

The following section outlines the data and methodology used to develop particulate emission factors for the lime industry.

4.1 REVIEW OF SPECIFIC DATA SETS

Some 45 reference documents were collected and reviewed during the literature search conducted as part of this study.[1-45] These documents are listed at the end of this section along with an indication as to whether the document contains particle size data.

The original group of 45 documents were reduced to a final set of 20 primary references utilizing the criteria outlined in Section 3.0. For those reference documents not used, the following summarizes the reason(s) for their rejection:

Reference No.	Cause(s) for Rejection
1	Not original source of test data.
2	Not original source of test data; no test method specified.
3	Not original source of test data.
4&5	Not original source of test data.
6	Incompatible test method.
7	Hours of operation not specified--could not calculate emission factor.

Reference No.	Cause(s) for Rejection
9	Lack of process data to calculate emission factors.
11	Test protocol not included with report.
15	Lack of process data to calculate emission factors.
16	Inaccurate process data.
18	Not original source of test data.
19	Inaccurate process data.
22	Lack of process data to calculate emission factors.
31	Data not applicable to lime industry (phosphate rock calciner and grinder).
33	Not original source of test data.
34	SO_2 emissions data only.
35	SO_2 emissions data only.
36	Not original source of test data.
37	Lack of process data to calculate emission factors.
38	Not original source of test data.
39	Test data not applicable to the lime industry (gypsum mill).
43	Not original source of test data.
44	Not original source of test data.

The following is a discussion of the data contained in each of the primary references used in the development of candidate emission factors, according to reference number and date of publication.

4.1.1 Reference 8 (1972)

Reference 8 is the trip report of a visit conducted by an EPA representative to the Paul Lime Company in Douglas, Arizona. Attached to this report were test data of the total mass emissions from a rotary kiln (No. 4) equipped with a gravel bed filter as determined by a private testing laboratory. Two compliance tests were conducted of kiln emissions using EPA Reference Method 5. The test results from both tests indicated a particulate emission rate including the impinger catch of 15 lb/hr (6.8 kg/hr) at a process weight rate of 15 short tons/hr (14 Mg/hr). Copies of appropriate portions of the test report are included in Appendix B.

Upon review of the test report, it was determined that only minimal documentation was presented on the sampling protocol used with no raw data included in the document. In addition, it is not entirely clear whether the process weight rate was input to or output from the kiln, although most regulations of this type are based on feed rate to the process. For this reason, a rating of C was assigned to the data in Reference 8.

4.1.2 Reference 10 (1973)

Reference 10 is the report of a compliance test conducted at the same plant as that described in Reference 8, except on a different kiln. This test was performed by the same private testing laboratory as indicated above for Reference 8. A somewhat larger kiln (No. 5) was tested in this case, however, which was fired with natural gas and equipped with a gravel bed filter. Three Method 5 tests were conducted with associated particulate emission rates (including the impinger catch) of 13.8, 9.9, and 10.9 lb/hr (6.27, 4.5, and 4.95 kg/hr), respectively, at a process weight rate of 25.2 short tons/hr (22.9 Mg/hr). Pertinent portions of the test report have likewise been included in Appendix B.

As with Reference 8, Reference 10 likewise contained only minimal documentation. Therefore, an identical rating of C was given to the data presented in Reference 10.

4.1.3 Reference 12, 14, 17, 20, 21, and 28 (1974-1975)

References 12, 14, 17, 20, 21, and 28 are source tests conducted by EPA contractors at nine different facilities for the purpose of developing NSPS for lime plants. All tests were performed at the outlet of a dust collector using standard EPA reference test methods.

The total mass emission factors presented in each document were generally reported in terms of pounds of pollutant per ton of feed to the process. In a number of cases, however, multiple stacks were tested making interpretation of the data slightly more difficult.

Several of the NSPS reports collected during the literature search were deleted from consideration due to either a lack of process data (References 15 and 22) or the presentation of inaccurate process data (References 16 and 19). In the case of References 15, 16, and 19, a conversion factor was needed to correct the raw stone totalizer readings obtained from control room data to the actual feed rate to the kiln. This factor was either not provided in the report (Reference 15), or was incorrectly reported as noted by the EPA project engineer (References 16 and 19). Finally, for Reference 22, no production data were presented in the report from which to calculate mass emission factors. Also, all of these tests were conducted nonisokinetically due to problems with high stack moisture.

Since all of the above tests were conducted more than 10 years ago and by contractors other than MRI, limitations in available funding precluded any attempt to resolve problems with the NSPS reports. A summary of the useable NSPS test data found during the literature review is shown in Table 4-1.

In the case of Reference 21, testing was conducted upstream of two baghouses controlling the emissions from a primary crusher and a primary screen/hammermill. There is some question as to the validity of this approach for accurately determining the uncontrolled emissions from processes generating fugitive emissions. It could be possible that the airflow created by the

TABLE 4-1. SUMMARY OF NSPS TEST DATA COLLECTED BY EPA

Ref. No.[a]	EPA report No.	Plant name/location	Sources tested	No. of tests	Emission factor measurement (lb/ton feed)[b]	Rating	Control device[c]	Comments
12	74-LIM-6	Dow Chemical Freeport, TX	(3) Gas-fired rotary kilns	3	0.234, 0.060, 0.112	B	(2) ESPs in parallel	Average of two stacks per test
14	74-LIM-1	Bethlehem Mines Corp. Annville, PA	Coal-fired rotary kiln	3	0.231, 0.297, 0.313	B	BH	Corrected for impinger catch
17	74-LIM-7	Marblehead Lime Co. Gary, IN	Coal-fired rotary kiln	6	Total for 6 stacks = 0.463	C	BH	1 test for each of 6 stacks on BH
20	74-LIM-5	U.S. Lime Division Flintkote Company City of Industry, CA	Atmospheric hydrator	3	0.065, 0.079, 0.107	C	Scrubber	2 out of 3 tests non-isokinetic
21	75-STN-7	J. H. Brenner Co. Lancaster, PA	Crusher, screen, & hammermill	3	0.001, 0.0004, 0.001	B	BH	
			Final screen	3	0.002, 0.00002, 0.0002	B	BH	
			Primary crusher	2	0.02, 0.02	Deleted	None	Uncontrolled
			Primary screen & hammermill	2	0.0006, 1.2	Deleted	None	Uncontrolled
24	--	Virginia Lime Company Ripplemead, VA	Coal-fired rotary kiln	3	203, 145, 151	B	None	Uncontrolled; values corrected for impinger catch
28	76-LIM-9	Martin-Marietta Corp. Roberta Cement Plant Calera, AL	Coal-fired rotary kiln	6	Combined Avg. of 3 Stacks = 0.0811	C	BH	2 tests/stack; 4 out of 6 runs nonisokinetic
			Atmospheric hydrator	3	0.0655, 0.113, 0.173	B	Scrubber	Emission factor calculated from data in test report
29	76-LIM-10	Allied Products Company Montevallo, AL	Coal/gas-fired rotary kiln	3	0.484, 0.345, 0.482,	B	Venturi scrubber (ΔP=15 in. H_2O)	Factors based on average input of 51.6 TPH
32	--	Standard Lime Company Woodville, OH	Coal-fired kiln and preheater	2	55.8, 16.2	B	Multiclone	
			Coal fired kiln	2	82.0, 74.7	B	Low eff. cyclone	

[a] From references listed at the end of Section 4.0.

[b] Based on front half of Method 5 train. 1 kg/Mg = 0.5 lb/short ton.

[c] ESP - electrostatic precipitator
BH - baghouse collector

ventilation system capturing emissions from the source will entrain larger particles which would not normally be emitted to the atmosphere if the process were exposed only to ambient wind conditions. This opinion is based on data collected in a study conducted for the National Crushed Stone Association in 1979 which compares emission factors determined by baghouse sampling to that obtained through source-specific ambient monitoring using a tracer.[46] The results of this study show significantly higher emission factors based on baghouse sampling for all sources tested as compared to those obtained from ambient monitoring. Sampling upstream of a dust collector could, therefore, tend to overpredict the uncontrolled emissions from such processes. This particular measurement problem is currently under investigation by the EPA and thus, only data collected downstream of the dust collector were used in this category report for the development of controlled emission factors for the above sources.

Upon review of References 12, 14, 17, 20, 21, and 28, it was determined that the sampling protocol used and test results obtained were reasonably well documented in each report. Due to the fact that these particular facilities represent well-controlled, operated, and maintained plants (as specified by NSPS), a rating of B was generally assigned to the data. For certain tests, where problems with isokinetic sampling were mentioned, a rating of C was assigned to the data (see Table 4-1). Copies of pertinent sections of each test report are included in Appendix B.

4.1.4 Reference 13 (1974)

Reference 13 is a compliance test conducted by a private consultant of the total mass emissions of particulate matter from a grate-type product cooler and a coal-fired rotary kiln located at a plant in Ohio. The cooler was uncontrolled and the kiln was equipped with a venturi scrubber. Sampling was conducted utilizing EPA Reference Method 5 at the cooler stack and the outlet of the venturi scrubber. Three tests were conducted in each case.

It was determined from the test data that the average particulate emission rate for the kiln and cooler were 52.9 and 12.2 lb/hr (24.0 and 5.54 kg/hr), respectively. The emissions from both sources were found not to be in compliance with future Ohio regulations. Appropriate exerpts from the test report have been included in Appendix B.

Upon review of Reference 13, it was determined that the amount of documentation contained in the report was minimal with no raw data (test or process) included. Also, since it was unclear as to how much of the cooler off-gas was recycled to the kiln during testing, these data were deleted from further consideration. Due to the lack of adequate documentation, a rating of C was assigned to the kiln data contained in Reference 13.

4.1.5 Reference 23 (1975)

Reference 23 is the report of a compliance test conducted by a private firm of the total mass emissions from a coal-fired rotary kiln equipped with a venturi scrubber. This particular study was a retest of the same kiln (kiln No. 1) mentioned above in Reference 13. Three tests were conducted at both the inlet and outlet of the scrubber using two different sampling trains.

At the scrubber inlet, a modified EPA Method 5 sampling train was used with the glass fiber filter placed behind the wet impingers. The inlet mass emission rate was calculated based on the total amount of material collected in the impingers and on the fiberglass filter. For outlet sampling, EPA Reference Method 5 was used with the emission rates reported both with and without the insoluble material collected in the wet impingers of the sampling train.

The results of the above tests indicated an average uncontrolled emission rate of 3,941 lb/hr (1,789 kg/hr) and an average controlled emission rate of 37.21 lb/hr (16.89 kg/hr), including both wet and dry catches. The emissions from the kiln were found to be in compliance with state standards. Pertinent sections of the test report are provided in Appendix B.

It was determined from a review of Reference 23, that reasonably good documentation was included in the report on the test procedures used and the results obtained. Because the tests conducted at the inlet varied significantly from standard sampling protocol, a rating of C was assigned to the inlet data. For the outlet tests, a rating of B was assigned to the data.

4.1.6 Reference 24 (1975)

Reference 24 is a source test conducted by an EPA contractor of the emissions of an uncontrolled coal-fired rotary kiln located at a plant in Virginia. The purpose of this test was to collect background data for the development of NSPS for the lime industry. The total mass emissions were determined using EPA Reference Method 5 with the particle size distribution measured utilizing a Brink Model BMS-11 cascade impactor. A cyclone precollector was also used in conjunction with the Brink impactor to capture the larger particles.

Three (complete) total mass and two impactor tests were conducted as part of the above study. The cut-point of the cyclone was not specified in the test report but was assumed to be 10 μmA (aerodynamic diameter) based on a computer printout obtained from the EADS-FPEIS data base (Test Series No. 00330). A summary of the particle size data contained in Reference 24 is shown in Table 4-2 with the Method 5 data presented previously in Table 4-1.

From an analysis of the data contained in Reference 24, it was determined that the particle size measurements were conducted using generally sound methodology and at least some field data are included in the report. However, the Brink impactor is generally not well suited to tests of uncontrolled sources with a substantial population of large particles since it is essentially a small particle sampler. In addition, since no standard precollector is supplied with the Brink impactor, one can never be certain of its cut-point without proper calibration.

TABLE 4-2. SUMMARY OF PARTICLE SIZE TEST DATA FOR REFERENCE 24 - UNCONTROLLED ROTARY KILN[a]

Data Rating: C

Impactor stage[b]	Test run No. 1 - 5/2/75 Mass collected (mg)	Cut-point (Dpc-μmA)[c]	Cumulative percent ≤ stated size	Test run No. 2 - 5/3/75 Mass collected (mg)	Cut-point (Dpc-μmA)[c]	Cumulative percent ≤ stated size
Cyclone[d]	67.30	10.0[e]	100.00	66.70	10.0[e]	100.00
1	0.45	2.77	3.55	0.59	1.96	2.92
2	0.46	1.62	2.90	0.14	1.13	2.06
3	0.10	1.10	2.24	0.21	0.75	1.85
4	0.12	0.56	2.10	0.10	0.36	1.55
5	0.14	0.34	1.93	0.06	0.18	1.40
Filter	1.20	< 0.34	1.72	0.90	< 0.18	1.32
Total mass emission factor (kg/Mg)[f]		203.2[g]			147.6[h]	

a Data taken from Table 7, p. 13 of test report (Appendix B). Emissions from an uncontrolled coal-fired rotary kiln.

b Brink Model BMS-11 cascade impactor with cyclone precollector.

c Aerodynamic diameter.

d Includes probe wash.

e Assumed based on FPEIS Test Series No. 00330.

f Factor expressed as kilograms of pollutant per metric ton (Mg = 10^6 g) of product per Table 1, p. 4, of test report (Appendix B).

g Emission factor based on loading determined in Test No. 3 less the mass collected in the impingers (see calculations in Appendix C).

h Average emission factor based on loadings determined in Tests Nos. 4 and 5 less mass collected in the impingers (see calculations in Appendix C).

Another potential source of error found in the report was the procedure of including the dried residue removed from the probe with that material collected in the cyclone. This assumes that all of the particles deposited in the probe are larger than the cut-point (i.e., 10 μmA) of the cyclone. Such an assumption has been found not to be the case by other investigators.[47] Based on the above factors, and the fact that the facility tested represents an especially well maintained and operated process (as required by NSPS procedures), a rating of B was assigned to the Method 5 data and a rating of C to the particle size data contained in Reference 24. A copy of pertinent sections of the test report and associated calculations are included in Appendices B and C, respectively.

4.1.7 Reference 25 (1975)

Reference 25 is a compliance test report of the total mass emissions from a coal-fired rotary kiln equipped with a stone preheater and gravel bed filter. Three tests were conducted at the outlet of the gravel bed filter using EPA Reference Method 5. The results of these tests indicate the total particulate emission rate to be 36, 37, and 35 lb/hr (16, 17, and 16 kg/hr) respectively, for the three runs at a stone feed rate of 61 short tons/hr (55 Mg/hr). Copies of appropriate portions of the test report have been included in Appendix B.

As with many compliance tests, the documentation included in Reference 25 was generally poor with little presented in the way of raw data. No process operating logs or similar information was included for validation of the process feed rate presented above. Due to the lack of adequate documentation, a rating of C was assigned to the data included in Reference 25.

4.1.8 Reference 26 (1975)

Reference 26 is a report of a compliance test of the total mass emissions from a coal-fired rotary kiln equipped with a venturi scrubber located at a plant in Ohio. Three tests were conducted at the outlet of the venturi scrubber using EPA Reference Method 5. From these tests, an average mass emission rate of 81.94 lb/hr (37.2 kg/hr) was determined for an average stone feed rate of 20.07 short tons/hr (18.21 Mg/hr). It was determined that from these tests the emissions from the kiln did not comply with applicable state standards. Appropriate sections of the test report have been included in Appendix B.

Upon review of the test report, it was determined that the information contained in Reference 26 did not include raw data sheets or other necessary information for adequate validation of the test results. Only summary data were presented for each test run. Due to the lack of adequate documentation, a rating of C was assigned to the data presented in Reference 26.

4.1.9 Reference 27 (1975)

Reference 27 is the report of a source test conducted by Marblehead Lime Company at their plant located in Bellefonte, Pennsylvania. These tests were performed of the combined emissions from three (3) coal-fired rotary kilns connected to two (2) baghouse collectors arranged in parallel. One test was conducted on four out of twelve identical baghouse sections utilizing an unspecified test method. However, from the format in which the data were presented, it was assumed that ASME Power Test Code 27 was used during these tests. Based on the test results, an average mass emission rate of 30.9 lb/hr (14.0 kg/hr) was determined for all three kilns. Applicable portions of the test reports are provided in Appendix B.

The documentation provided in Reference 27 was at best minimal. Only summary information was presented in the report and that which was provided was grossly incomplete. Due to the lack of documentation and the fact that no test method was specified, a rating of D was assigned to the data contained in Reference 27.

4.1.10 Reference 29 (1975)

Reference 29 is a companion study to those described above for the development of NSPS for the lime industry. In this study, the total mass emissions from a rotary kiln fired with a combination of coal and natural gas were determined at the exit of a venturi scrubber (controlled emissions). Particle size tests were conducted downstream of a Buell multiple cyclone dust collector between the multicyclone and venturi scrubber using a Brink Model BMS-11 cascade impactor and cyclone precollector. No tests for total mass loading were conducted at the multiclone outlet, and therefore only particle size data are available at this sampling location. Three Brink impactor runs were conducted during the study. The particle size data obtained during the sampling program is summarized in Table 4-3 with the total mass data shown previously in Table 4-1.

An analysis of the data contained in Reference 29 showed adequate documentation of a generally sound technical approach. However, similar problems to that described earlier for Reference 24, were also noted for this study as well. In addition, during the first Brink test the impactor was overloaded thus invalidating the resulting data. Based on the various factors and sources of potential experimental error mentioned above, a rating of B was assigned to the Method 5 data and a rating of C to the particle size data contained in Reference 29. A copy of pertinent sections of the test report are included in Appendix B.

4.1.11 Reference 32 (1975)

Reference 32 is another NSPS test of the emissions from two coal-fired rotary kilns equipped with a cyclone and baghouse collector. During these tests, one kiln (No. 4) was producing dolomitic quicklime and the other (No. 6) dead burn (or refractory) lime. On kiln No. 4, total mass loading and particle size distribution data were collected between the multiple cyclone dust collector and baghouse. On kiln No. 6, similar tests were conducted between a low-efficiency cyclone and baghouse.

The total mass emissions from both kilns was measured using EPA Reference Method 5 with the particle size distribution determined using a Brink Model BMS-11 cascade impactor with cyclone precollector. Two Method-5 tests

TABLE 4-3. SUMMARY OF PARTICLE SIZE DATA FOR REFERENCE 29 - VENTURI SCRUBBER INLET[a]

Data Rating: C

Impactor[b]	Test No. 1 - 9/15/75[c] Mass collected (mg)	Cut-point (Dpc-μm)[d]	Cumulative percent ≤ stated size	Test No. 2 - 9/16/75 Mass collected (mg)	Cut-point (Dpc-μm)[d]	Cumulative percent ≤ stated size	Test No. 3 - 9/16/75 Mass collected (mg)	Cut-point (Dpc-μm)[d]	Cumulative percent ≤ stated size
Cyclone[e]	85.800	10.0[f]	100.00	70.600	10.0[f]	100.00	73.600	10.0[f]	100.00
1	8.366	4.63	12.11	2.060	5.06	5.93	2.431	4.79	6.09
2	0.915	2.73	3.55	1.210	3.00	3.19	1.004	2.83	2.99
3	1.000	1.87	2.61	0.490	2.05	1.58	0.137	1.94	1.72
4	0.240	0.98	1.58	0.150	1.09	0.93	0.120	1.02	1.54
5	0.206	0.61	1.34	0.150	0.70	0.73	0.092	0.64	1.39
Filter	1.100	0.30	1.13	0.400	0.30	0.53	1.000	0.30	1.27

a Data taken from Table 7, page 17 of test report (Appendix B). Measurements made at the outlet of a multiple cyclone collector used on a combination coal and natural gas-fired rotary kiln. No total mass data available at this sampling location.

b Brinks Model BMS-11 cascade impactor with cyclone precollector.

c Impactor overloaded during sampling thus invalidating test results.

d Aerodynamic diameter.

e Includes probe wash.

f Assumed based on FPEIS Test Series No. 00330.

and one cascade impactor test were conducted on each kiln. A summary of the data obtained from these tests is shown in Table 4-4 with the Method 5 results also shown previously in Table 4-1.

It was determined from a review of the information contained in Reference 32 that adequate documentation was presented in the report and that generally sound methodology was used. The most major problem noted was the fact that only one particle size test was conducted on each kiln. This lack of duplicity coupled with other pertinent factors mentioned above resulted in a rating of B being assigned to the Method 5 data and a rating of C to the particle size data shown in Table 4-4. A copy of appropriate portions of the report along with associated calculations are provided in Appendices B and C, respectively.

4.1.12 Reference 40 (1977)

Reference 40 is a source test report supplied by the National Lime Association as Exhibit 2. During the tests conducted, the total mass emission rate was determined at the outlet of a baghouse controlling the emissions from a coal-fired rotary kiln. One test was performed on each of the six baghouse stacks using EPA Reference Method 5. From the data presented, a total mass emission rate of 17.71 lb/hr (8.040 kg/hr) was determined for an average limestone feedrate of 42.9 short tons/hr (38.9 Mg/hr). Excerpts from the test report have been included in Appendix B.

Upon review of the above test report, it was determined that the data are of relatively good quality. However, details on the operation of the process and the associated emissions control equipment are lacking. For this reason, and the fact that only one test was performed on each stack, a rating of B was assigned to the test data reported in Reference 40.

4.1.13 Reference 41 (1977)

Reference 41 is a retest of the same kiln and baghouse included in Reference 40 above. In this case, however, triplicate tests were conducted on only one of six baghouse sections after the installation of new bags.

TABLE 4-4. SUMMARY OF PARTICLE SIZE DATA FOR REFERENCE 32 - BAGHOUSE INLET[a]

Data Rating: C

Impactor stage[b]	Kiln 4 - 12/9/75[c] Mass collected (mg)	Kiln 4 Cut-point (Dpc-μmA)[e]	Kiln 4 Cumulative percent ≤ stated size	Kiln 6 - 12/9/75[d] Mass collected (mg)	Kiln 6 Cut-point (Dpc-μmA)[e]	Kiln 6 Cumulative percent ≤ stated size
Cyclone[f]	60.600	10.0[g]	100.00	88.400	10.0[g]	100.00
1	21.100	2.30	39.28	7.360	3.09	21.16
2	9.100	1.26	18.14	9.220	1.70	14.59
3	2.900	0.79	9.02	1.460	1.07	6.37
4	2.800	0.32	6.11	1.230	0.45	5.07
5	2.600	0.16	3.31	3.650	0.23	3.97
Filter	0.700	≤ 0.16	0.70	0.800	< 0.23	0.71
Total mass emission factor (kg/Mg)[h]		64.6[i]			102.5[j]	

a Data taken from Table 4, page 10 of test report (Appendix B). Emissions from two separate coal-fired rotary kilns.

b Brink Model BMS-11 cascade impactor with cyclone precollector.

c Data collected downstream of multiclone. Kiln producing dolomitic quicklime.

d Data collected downstream of low-efficiency cyclone. Kiln producing dead burn dolomitic lime.

e Aerodynamic diameter.

f Includes probe wash.

g Assumed from EADS printout for FPEIS Test Series No. 00330.

h Data taken from Table 1, page 4 of test report (Appendix B). Expressed as kilograms of emissions per metric ton (1 Mg = 10^6 g) of product.

i Emission factor for Method 5 Run Nos. 1-4 from Table 1, page 4 of the test report (Appendix B).

j Average emission factor for Method 5 Run Nos. 1-6 and 2-6 from Table 1, page 4 of the test report (Appendix B).

EPA Reference Method 5 was again used to determine the total particulate emissions from the baghouse stack. Using the test data as applied to the entire baghouse, an average emission factor of 0.515 lb of particulate/short ton of limestone feed (0.258 kg/Mg) was obtained. Copies of pertinent sections of the test report are provided in Appendix B.

Since the above tests were performed in almost an identical manner and with essentially identical documentation as that in Reference 40, a rating of B was likewise assigned to the data contained in Reference 41.

4.1.14 Reference 42 (1977)

Reference 42 is the report of a source test conducted on the same plant included in Reference 27 above. The emissions from three coal-fired rotary kilns equipped with two parallel baghouses were tested using EPA Reference Method 5. Initially, one test was conducted on each of two sections of each baghouse equipped with existing bags. Finally, duplicate tests were performed on a single section of one baghouse (i.e., A4) after replacement of the bags. The data obtained from these tests were:

Baghouse Section No.	Particulate Emission Factor lb/ton feed	kg/Mg feed
B1	0.87	0.44
A4 (existing bags)	1.60	0.800
B4	1.54	0.770
A1	0.77	0.39
A4 (new bags)	0.68	0.34
A4 (new bags)	0.77	0.39

Applicable portions of the test report have been provided in Appendix B.

A review of the information contained in Reference 42 indicated a generally sound technical approach. However, documentation of certain key test data (e.g., raw tare and final weights) was found to be deficient. The lack of documentation coupled with the fact that only single (or at best duplicate) tests were conducted on each stack, a rating of C was assigned to the test data reported in Reference 42.

4.1.15 Reference 45 (1983)

The final reference used to develop candidate emission factors was a study conducted by MRI under the IP program at a plant located in Ohio. Testing was conducted of the emissions from four sources: two coal-fired rotary kilns (Nos. 6 and 7); a belt conveyor dust collection system; and a truck loading bay. One of the rotary kilns was equipped with a cyclone and baghouse collector and the other with an electrostatic precipitator.

Particulate matter contained in the exhaust gas of both kilns was determined at the inlet and outlet of either the baghouse or electrostatic precipitator utilizing the sampling protocol developed especially for the IP program. For kiln No. 6 (equipped with the baghouse) sampling was conducted both immediately downstream of a single cyclone and at the outlet of one of the five chambers comprising the baghouse collector. Testing on kiln No. 7 was performed at the inlet and outlet of one of three parallel ESP modules controlling emissions from the kiln. Kiln No. 7 had no primary collector upstream of the ESP.

Total mass emissions from the two kilns were determined using EPA Reference Method 5 with the inlet particle size distribution measured using a Brink Model B cascade impactor with 7 µmA cyclone precollector. The outlet particle size distribution was determined with an Andersen Mark III impactor and a Sierra instruments 15 µmA cyclone preseparator. A total of 16 tests for both total mass and particle size were conducted during the study for both kilns.

Testing on the conveyor dust collection system was performed in one of the main branch ducts upstream of a central baghouse collector. This duct connected 13 individual dust collection points located at various drop locations and transfer belts handling finished product. Samples were also collected using the standard IP protocol mentioned above. Due to budgetary constraints, no tests were conducted of the emissions at the outlet from the baghouse. The total mass loading for the belt conveyor system was determined using EPA Method 5 and particle size using the Andersen impactor described above. A total of 16 total mass tests and 16 particle size tests were performed on the conveyor dust collection system as part of the study.

As stated in Section 4.1.3, there is some question as to the validity of using test data from a ventilation system upstream of the dust collector to determine the uncontrolled emissions from a source of fugitive particulate emissions. The data so obtained could represent uncharacteristically high emission rates which would not occur if the source was not equipped with such a system and exposed only to ambient winds. For this reason, the data presented in Reference 45 for the emissions from product transfer were not used in the development of candidate emission factors, and thus not included in this report.

Fugitive dust emissions from the truck loading bay were determined during the loading pulverized agricultural limestone into open and closed trucks and the loading of glass lime into closed trucks. A total of five tests were conducted; four of agricultural limestone and one of glass lime. The emissions were determined by measuring the total mass flux of particulate eminating from the bay which was completely enclosed except for the truck entrance and exit. A modified upwind/downwind method was used according to guidelines published in the IP protocol document for fugitive sources.

The overall sampling strategy used to quantify the fugitive emissions during truck loading involved a determination of the net downwind particulate concentration (and size distribution) at various locations and sampling heights in the exit from the loading bay. The total airflow through the loading area was determined from traverses using warm-wire anemometers. Background particulate concentrations measured in the upwind direction were subsequently used to calculate the net mass particle flux from the loading bay. Truck mounted samplers were used for the downwind measurements consisting of one standard high volume air sampler (hi-vol), two hi-vols equipped with Andersen 15 μmA size-selective inlets, and three additional hi-vols equipped with a Sierra Model 230-CP cyclone preseparator and Model 230 five-stage cascade impactor, respectively. The background samples were collected utilizing one of each type instrument.

Tables 4-5 through 4-13 provide a summary of the results of this study with a copy of applicable portions of the document included in Appendix B. Since the tests in Reference 45 were conducted according to the protocol developed for the IP program and are well documented, a rating of A was assigned to the data.

4.2 RESULTS OF DATA ANALYSIS

4.2.1 Total Mass Emissions Data

Both uncontrolled and controlled mass emission factors were determined from the data contained in each of the reference documents described above for total particulate. In the case of uncontrolled emissions, only References 23, 24, and 45 contained useful data. For References 23 and 24, the emission factors were determined either by hand calculation from the raw test data or by correction for the impinger catch. A copy of these calculations along with pertinent portions of the test report and any assumptions made are shown in Appendix C. With regard to Reference 45, appropriate emission factors have already been presented in the test report and thus were only extracted from such (after conversion to metric units). A summary of the available uncontrolled mass emissions for total particulate as determined from the various reference documents is shown in Table 4-14.

For controlled sources, a procedure similar to that described above for determining uncontrolled emission factors was used. References 8, 10, 12, 13, 14, 17, 20, 21, 23, 25, 26, 27, 28, 29, 32, 40, 41, 42, and 45 contained useful data. Except for References 32 and 45, the controlled emission factors were calculated by hand from emission factors expressed in terms other than mass of pollutant per metric ton of lime produced, from the raw test data, or by adjustment of the emission rates presented for the mass collected in the wet impingers of the sampling train. These calculations are likewise shown in Appendix C with a complete summary of all available controlled emission factors for total particulate shown in Table 4-14.

TABLE 4-5. SUMMARY OF PARTICLE SIZE DATA FOR REFERENCE 45 - KILN NO. 6 BAGHOUSE INLET[a]
Data Rating: A

Run No.	7 µm Cyclone Mass (mg)[b]	7 µm Cyclone D_{50} size (µmA)[c]	7 µm Cyclone Cum. % less than[d]	Stage 1 Mass (mg)[b]	Stage 1 D_{50} size (µmA)[c]	Stage 1 Cum. % less than[d]	Stage 2 Mass (mg)[b]	Stage 2 D_{50} size (µmA)[c]	Stage 2 Cum. % less than[d]	Stage 3 Mass (mg)[b]	Stage 3 D_{50} size (µmA)[c]	Stage 3 Cum. % less than[d]	Stage 4 Mass (mg)[b]	Stage 4 D_{50} size (µmA)[c]	Stage 4 Cum. % less than[d]
Bag-I-1-1	58.77	7.00	28.56	1.06	3.33	27.28	11.06	1.95	13.83	6.92	1.31	5.42	1.44	0.67	3.67
Bag-I-1-2	28.40	7.00	34.00	2.36	4.38	28.51	8.45	2.58	8.88	2.35	1.76	3.42	1.03	0.92	1.02
Bag-I-1-3	49.30	7.00	31.52	3.16	3.81	27.13	15.60	2.23	5.46	2.77	1.51	1.61	1.16	0.77	0.00
Bag-I-1-4	34.32	7.00	25.34	6.59	4.20	11.01	4.16	2.47	1.96	0.90	1.68	0.00	0.00	0.87	0.00
Bag-I-2-1	46.40	7.00	34.19	3.48	3.51	29.26	15.97	2.05	6.61	3.43	1.39	1.74	0.71	0.71	0.74
Bag-I-2-2(2)[e]	0.00	7.00	100.00	3.27	4.47	92.82	4.71	2.64	82.47	4.37	1.80	72.88	1.31	0.94	70.00
Bag-I-2-3(2)	50.57	7.00	29.81	11.28	3.57	14.15	6.47	2.09	5.17	1.98	1.41	2.41	0.90	0.72	1.16
Bag-I-2-4	38.16	7.00	33.41	2.39	4.48	29.24	8.35	2.64	14.67	7.44	1.80	1.69	0.67	0.94	0.52
Bag-I-3-1	33.47	7.00	33.93	7.99	3.16	18.15	5.82	1.85	6.66	1.91	1.25	2.88	0.83	0.63	1.23
Bag-I-3-2	25.70	7.00	43.17	1.81	3.93	39.16	9.04	2.31	19.17	7.28	1.56	3.07	0.88	0.81	1.13
Bag-I-3-3(2)	40.30	7.00	34.78	3.57	4.03	28.99	13.53	2.37	7.09	2.61	1.61	2.86	0.90	0.83	1.40
Bag-I-3-4	42.57	7.00	28.10	7.25	4.25	15.85	5.87	2.50	5.93	2.10	1.70	2.38	0.47	0.88	1.58
Bag-I-4-1	50.00	7.00	25.88	8.50	3.45	13.28	5.15	2.02	5.64	2.00	1.37	2.67	0.77	0.70	1.52
Bag-I-4-2	30.67	7.00	35.03	2.20	4.24	30.36	9.19	2.49	10.89	2.66	1.69	5.25	1.67	0.88	1.70
Bag-I-4-3	70.11	7.00	28.81	12.41	3.61	16.20	11.18	2.11	4.85	2.92	1.43	1.88	0.94	0.73	0.92
Bag-I-4-4(2)	23.10	7.00	33.35	4.39	4.35	20.67	4.60	2.56	7.39	1.98	1.74	1.67	0.50	0.91	0.21

Run No.	Stage 4 Mass (ab)[b]	Stage 4 D_{50} size (µmA)[c]	Stage 4 Cum. % less than[d]	Stage 5 Mass (mg)[b]	Stage 5 D_{50} size (µmA)[c]	Stage 5 Cum. % less than[d]	Filter Mass (mg)[b]	Filter D_{50} size (µmA)[c]	Total mass (mg)[b]
Bag-I-1-1	1.44	0.67	3.67	3.02	0.40	0.00	0.00	< 0.40	82.27
Bag-I-1-2	1.03	0.92	1.02	0.44	0.58	0.00	0.00	< 0.58	
Bag-I-1-3	1.16	0.77	0.00	0.00	0.47	0.00	0.00	< 0.47	
Bag-I-1-4	0.00	0.87	0.00	0.00	0.54	0.00	0.00	< 0.54	
Bag-I-2-1	0.71	0.71	0.74	0.52	0.42	0.00	0.00	< 0.42	
Bag-I-1-2(2)[e]	1.31	0.94	70.00	0.42	0.60	69.07	31.48	< 0.60	
Bag-I-2-3(2)	0.90	0.72	1.16	0.13	0.44	0.98	0.71	< 0.44	
Bag-I-2-4	0.67	0.94	0.52	0.29	0.59	0.02	0.01	< 0.59	
Bag-I-3-1	0.83	0.63	1.23	0.62	0.38	0.00	0.00	< 0.38	
Bag-I-3-2	0.88	0.81	1.13	0.45	0.50	0.13	0.06	< 0.50	
Bag-I-3-3(2)	0.90	0.83	1.40	0.86	0.52	0.00	0.00	< 0.52	
Bag-I-3-4	0.47	0.88	1.58	0.19	0.55	1.26	0.75	< 0.55	
Bag-I-4-1	0.77	0.70	1.52	0.61	0.42	0.61	0.41	< 0.42	
Bag-I-4-2	1.67	0.88	1.70	0.51	0.55	0.61	0.29	< 0.55	
Bag-I-4-3	0.94	0.73	0.92	0.09	0.45	0.83	0.82	< 0.45	
Bag-I-4-4(2)	0.50	0.91	0.21	0.07	0.57	0.00	0.00	< 0.57	

[a] Data taken from Table 3-4, page 45 of test report (Appendix B). Emissions from coal-fired rotary kiln downstream of a cyclone collector. Brink impactor data.

[b] mg = milligrams.

[c] D_{50} - cut-point of cyclone or impactor stage in micrometers (µmA - aerodynamic diameter).

[d] Cumulative percent less than or equal to stated D_{50}.

[e] Not used in calculations due to suspect stage loading.

TABLE 4-6. SUMMARY OF PARTICLE SIZE DATA FOR REFERENCE 45 - KILN No. 6 BAGHOUSE OUTLET[a]

Data Rating: A

Run No.	15 µm Cyclone Mass (mg)[b]	15 µm Cyclone D_{50} size (µmA)[c]	15 µm Cyclone Cum. % less than[d]	Stage 0 Mass (mg)[b]	Stage 0 D_{50} size (µmA)[c]	Stage 0 Cum. % less than[d]	Stage 1 Mass (mg)[b]	Stage 1 D_{50} size (µmA)[c]	Stage 1 Cum. % less than[d]	Stage 2 Mass (mg)[b]	Stage 2 D_{50} size (µmA)[c]	Stage 2 Cum. % less than[d]	Stage 3 Mass (mg)[b]	Stage 3 D_{50} size (µmA)[c]	Stage 3 Cum. % less than[d]
Bag-0-1-1	4.47	15.16	20.29	0.00	15.16	20.29	0.06	9.45	19.15	0.00	6.40	19.15	0.12	4.35	16.95
Bag-0-1-2	0.19	16.06	86.00	0.20	15.94	71.45	0.00	9.94	71.48	0.00	6.73	71.45	0.23	4.57	54.66
Bag-0-1-3(2)	4.44	15.80	55.36	0.21	15.80	53.24	0.98	9.85	43.37	0.88	6.67	34.51	0.87	4.54	25.75
Bag-0-1-4	0.00	15.33	100.00	0.32	15.33	88.23	0.35	9.56	75.36	0.38	6.47	61.41	0.33	4.40	49.27
Bag-0-2-1	1.07	15.65	78.53	0.52	15.65	68.05	0.25	9.76	62.98	0.39	6.61	55.10	0.38	4.49	47.43
Bag-0-2-2(2)	0.00	16.34	100.00	1.28	16.24	88.28	1.13	10.13	77.94	1.15	6.88	67.41	1.31	4.66	55.42
Bag-0-2-3	14.89	15.31	20.07	0.80	15.31	17.37	0.41	9.55	15.55	0.43	6.46	12.82	0.53	4.39	9.96
Bag-0-2-4	0.00	15.25	100.00	0.71	15.25	83.59	0.50	9.50	72.03	0.38	6.43	63.19	0.49	4.37	51.84
Bag-0-3-1	0.38	16.13	96.54	1.15	16.08	85.94	0.87	10.03	77.93	1.33	6.79	65.67	1.25	4.61	54.15
Bag-0-3-2(2)	0.08	16.18	99.19	0.00	16.18	99.19	0.00	10.09	99.19	0.00	6.84	99.19	1.05	4.65	82.05
Bag-0-3-3	126.01	15.49	12.02	0.00	15.49	12.02	0.00	9.66	12.02	0.00	6.54	12.02	2.03	4.44	10.60
Bag-0-3-4	0.96	15.49	72.14	0.00	15.49	72.14	0.00	9.65	72.14	0.13	6.53	68.33	0.42	4.44	56.11
Bag-0-4-1(2)	1.33	15.59	84.95	0.40	15.59	80.41	0.27	9.72	77.34	0.69	6.58	69.52	0.99	4.47	58.30
Bag-0-4-2	0.08	16.07	99.39	2.13	16.61	84.08	1.65	10.36	72.21	1.46	7.01	61.72	1.55	4.77	50.58
Bag-0-4-3	1.65	15.54	87.68	1.02	15.54	80.05	0.76	9.69	74.37	1.14	6.56	65.84	1.01	4.46	58.29
Bag-0-4-4	1.65	15.84	76.82	0.66	15.84	67.54	0.20	9.88	64.71	0.55	6.69	56.97	0.93	4.55	43.89

Run No.	Stage 4 Mass (mg)[b]	Stage 4 D_{50} size (µmA)[c]	Stage 4 Cum. % less than[d]	Stage 5 Mass (mg)[b]	Stage 5 D_{50} size (µmA)[c]	Stage 5 Cum. % less than[d]	Stage 6 Mass (mg)[b]	Stage 6 D_{50} size (µmA)[c]	Stage 6 Cum. % less than[d]	Stage 7 Mass (mg)[b]	Stage 7 D_{50} size (µmA)[c]	Stage 7 Cum. % less than[d]	Filter Mass (mg)[b]	Filter D_{50} size (µmA)[c]
Bag-0-1-1	0.36	2.78	10.47	0.44	1.37	2.56	0.14	0.83	0.00	0.00	0.55	0.00	0.00	< 0.55
Bag-0-1-2	0.20	2.93	40.04	0.47	1.45	6.01	0.08	0.88	0.00	0.00	0.59	0.00	0.00	< 0.59
Bag-0-1-3(2)	0.87	2.90	16.99	1.23	1.44	4.62	0.27	0.87	1.89	0.04	0.58	1.47	0.15	< 0.58
Bag-0-1-4	0.37	2.81	35.68	0.68	1.39	10.82	0.18	0.84	4.14	0.11	0.56	0.00	0.00	< 0.56
Bag-0-2-1	0.72	2.87	32.95	0.83	1.42	16.28	0.49	0.86	6.40	0.10	0.57	4.33	0.22	< 0.57
Bag-0-2-2(2)	1.75	2.98	39.41	1.76	1.48	23.30	1.23	0.90	12.04	0.90	0.60	3.80	0.42	< 0.60
Bag-0-2-3	0.53	2.81	7.09	0.74	1.39	3.10	0.35	0.84	1.20	0.22	0.56	0.00	0.00	< 0.56
Bag-0-2-4	0.68	2.79	36.12	0.74	1.38	19.02	0.47	0.83	8.13	0.35	0.55	0.00	0.00	< 0.55
Bag-0-3-1	1.71	2.95	38.39	1.68	1.46	22.90	1.12	0.89	12.58	0.91	0.59	4.19	0.45	< 0.59
Bag-0-3-2(2)	1.92	2.98	50.74	2.22	1.48	14.54	0.57	0.90	5.23	0.32	0.61	0.00	0.00	< 0.61
Bag-0-3-3	3.99	2.84	7.81	7.71	1.40	2.43	3.14	0.85	0.23	0.33	0.57	0.00	0.00	< 0.57
Bag-0-3-4	0.65	2.84	37.21	1.16	1.40	3.52	0.12	0.85	0.00	0.00	0.56	0.00	0.00	< 0.56
Bag-0-4-1(2)	1.34	2.86	43.12	1.67	1.41	24.21	0.49	0.86	18.65	0.15	0.57	16.94	1.50	< 0.57
Bag-0-4-2	1.89	3.05	36.99	1.85	1.51	23.69	1.48	0.92	13.05	1.09	0.61	5.21	0.73	< 0.61
Bag-0-4-3	1.57	2.85	46.56	2.57	1.41	27.35	2.00	0.85	12.41	1.66	0.57	0.00	0.00	< 0.57
Bag-0-4-4	1.18	2.91	27.30	1.46	1.44	6.78	0.41	0.88	1.00	0.07	0.59	0.00	0.00	< 0.59

[a] Data taken from Table 3-4, page 46 of test report (Appendix B). Emissions from coal-fired rotary kiln downstream of a baghouse collector. Andersen impactor data.

[b] mg = milligrams.

[c] D_{50} - cut-point of cyclone or impactor stage in micrometers (µmA - aerodynamic diameter).

[d] Cumulative percent less than or equal to stated D_{50}.

[e] Not used in calculations due to suspect stage loading.

TABLE 4-7. SUMMARY OF PARTICLE SIZE DATA FOR REFERENCE 45 - KILN NO. 7 ELECTROSTATIC PRECIPITATOR INLET[a]
Data Rating: A

Run No.	7 µm Cyclone Mass, (mg)[b]	7 µm Cyclone D_{50} size (µmA)[c]	7 µm Cyclone Cum. % less than[d]	Stage 1 Mass, (mg)[b]	Stage 1 D_{50} size (µmA)[c]	Stage 1 Cum. % less than[d]	Stage 2 Mass, (mg)[b]	Stage 2 D_{50} size (µmA)[c]	Stage 2 Cum. % less than[d]	Stage 3 Mass, (mg)[b]	Stage 3 D_{50} size (µmA)[c]	Stage 3 Cum. % less than[d]
ESP-I-1-1	244.42	7.00	5.80	9.31	3.93	2.21	2.80	2.29	1.13	0.94	1.55	0.77
ESP-I-1-2	205.03	7.00	5.49	6.52	4.00	2.48	3.24	2.34	0.99	0.58	1.58	0.72
ESP-I-1-3(2)	284.14	7.00	5.64	9.83	4.14	2.37	3.51	2.41	1.21	1.10	1.63	0.84
ESP-I-1-4(2)	295.16	7.00	4.89	8.21	4.56	2.24	4.29	2.67	0.86	1.19	1.81	0.48
ESP-I-2-1	144.85	7.00	11.21	12.61	4.16	3.48	4.27	2.43	0.86	0.74	1.64	0.40
ESP-I-2-2	212.54	7.00	6.93	9.82	4.00	2.63	3.17	2.34	1.24	0.62	1.58	0.88
ESP-I-2-3	237.04	7.00	5.68	8.59	4.26	2.27	2.94	2.49	1.19	0.77	1.68	0.79
ESP-I-2-4	392.14	7.00	8.05	25.03	4.11	2.18	6.06	2.40	0.75	1.48	1.62	0.41
ESP-I-3-1	297.77	7.00	5.47	11.38	4.23	1.85	3.39	2.47	0.77	0.76	1.67	0.53
ESP-I-3-2	221.67	7.00	6.69	10.14	4.09	2.42	4.14	2.39	0.67	0.88	1.62	0.30
ESP-I-3-3	231.96	7.00	5.25	8.62	4.11	1.72	3.12	2.40	0.46	0.50	1.62	0.25
ESP-I-3-4	383.07	7.00	5.02	14.67	3.84	1.39	3.48	2.24	0.52	0.90	1.51	0.30
ESP-I-4-1	236.77	7.00	6.07	9.64	4.24	2.24	3.21	2.48	0.97	0.87	1.67	0.62
ESP-I-4-2(2)	281.92	7.00	5.61	4.65	4.19	4.06	10.77	2.45	0.45	0.68	1.66	0.22
ESP-I-4-3	252.63	7.00	5.99	10.60	4.16	2.04	3.96	2.43	0.57	0.90	1.64	0.23
ESP-I-4-4	352.38	7.00	6.39	14.92	3.88	2.42	6.00	2.26	0.83	1.15	1.52	0.52

Run No.	Stage 4 Mass, (mg)[b]	Stage 4 D_{50} size (µmA)[c]	Stage 4 Cum. % less than[d]	Stage 5 Mass, (mg)[b]	Stage 5 D_{50} size (µmA)[c]	Stage 5 Cum. % less than[d]	Filter Mass, (mg)[b]	Filter D_{50} size (µmA)[c]
ESP-I-1-1	0.47	0.78	0.59	0.31	0.47	0.47	1.21	< 0.47
ESP-I-1-2	0.20	0.81	0.63	0.27	0.49	0.50	1.08	< 0.49
ESP-I-1-3(2)	0.73	0.83	0.60	0.47	0.50	0.44	1.32	< 0.50
ESP-I-1-4(2)	0.57	0.93	0.29	0.75	0.57	0.05	0.15	< 0.57
ESP-I-2-1	0.36	0.84	0.18	0.13	0.51	0.10	0.16	< 0.51
ESP-I-2-2	0.26	0.80	0.77	0.65	0.49	0.48	1.10	< 0.49
ESP-I-2-3	0.19	0.86	0.71	0.67	0.52	0.44	1.11	< 0.52
ESP-I-2-4	0.80	0.82	0.22	0.93	0.49	0.00	0.00	< 0.49
ESP-I-3-1	0.27	0.85	0.45	0.34	0.52	0.34	1.07	< 0.52
ESP-I-3-2	0.28	0.83	0.18	0.08	0.50	0.15	0.36	< 0.50
ESP-I-3-3	0.14	0.82	0.19	0.36	0.50	0.05	0.11	< 0.50
ESP-I-3-4	0.31	0.76	0.22	0.30	0.45	0.15	0.59	< 0.45
ESP-I-4-1	0.41	0.85	0.46	0.30	0.52	0.34	0.65	< 0.52
ESP-I-4-2(2)	0.21	0.85	0.15	0.12	0.52	0.11	0.33	< 0.52
ESP-I-4-3	0.47	0.84	0.05	0.00	0.51	0.05	0.14	< 0.51
ESP-I-4-4	0.57	0.76	0.37	0.90	0.45	0.13	0.50	< 0.45

[a] Data taken from Table 3-6, page 60 of the test report (Appendix B). Emissions from a coal-fired rotary kiln upstream of an electrostatic precipitator. Brink impactor data.

[b] mg = milligrams.

[c] D_{50} - cut-point of cyclone or impactor stage in micrometers (µmA - aerodynamic diameter).

TABLE 4-8. SUMMARY OF PARTICLE SIZE DATA FOR REFERENCE 45 - KILN NO. 7 ELECTROSTATIC PRECIPITATOR OUTLET[a]

Data Rating: A

Run No.	7 µm Cyclone Mass (mg)[b]	7 µm Cyclone D_{50} size (µmA)[c]	7 µm Cyclone Cum. % less than[d]	Stage 0 Mass (mg)[b]	Stage 0 D_{50} size (µmA)[c]	Stage 0 Cum. % less than[d]	Stage 1 Mass (mg)[b]	Stage 1 D_{50} size (µmA)[c]	Stage 1 Cum. % less than[d]	Stage 2 Mass (mg)[b]	Stage 2 D_{50} size (µmA)[c]	Stage 2 Cum. % less than[d]
ESP-0-1-2(2)	64.13	12.97	33.47	1.67	12.64	31.73	1.94	7.86	29.72	8.34	5.30	21.07
ESP-0-1-2(2)	25.14	13.40	96.20	5.28	12.98	59.06	1.94	8.07	56.45	6.79	5.45	47.31
ESP-0-1-3	47.63	12.61	49.35	1.43	12.36	47.83	3.10	7.68	44.53	13.85	5.18	29.80
ESP-0-1-4	17.67	12.75	67.49	1.53	12.45	64.68	2.17	7.74	60.68	8.95	5.22	44.21
ESP-0-2-1	56.27	13.11	41.51	4.94	12.70	36.38	2.36	7.90	33.92	8.31	5.33	25.29
ESP-0-2-2	23.58	15.32	61.93	6.73	14.45	51.06	3.62	9.00	45.21	7.73	6.08	32.73
ESP-0-2-3	114.26	14.95	34.76	2.12	14.14	33.55	2.17	8.00	32.31	13.62	5.94	24.53
ESP-0-2-4	29.84	13.53	55.74	1.36	13.13	53.72	1.99	8.17	50.77	9.74	5.51	36.52
ESP-0-3-1	44.68	13.13	59.58	5.38	12.72	54.70	4.68	7.91	50.47	12.88	5.34	38.80
ESP-0-3-2	22.21	14.04	62.28	0.84	13.48	60.85	1.60	8.39	58.14	7.06	5.66	46.14
ESP-0-3-3	34.02	15.30	49.00	2.66	14.44	45.02	1.36	8.99	42.98	6.92	6.07	32.60
ESP-0-3-4	17.02	15.02	65.98	1.85	14.22	62.29	1.12	8.85	60.05	5.27	5.98	49.53
ESP-0-4-1	64.23	13.43	49.67	3.67	12.90	46.79	6.18	8.02	41.95	17.47	5.41	28.26
ESP-0-4-2	14.33	14.01	74.49	1.92	13.40	71.07	2.95	8.34	65.81	10.58	5.63	46.97
ESP-0-4-3	67.35	16.74	27.28	0.91	15.43	86.30	1.20	9.60	25.00	4.98	6.49	19.63
ESP-0-4-4(2)	18.96	15.81	54.31	0.43	14.82	53.27	0.38	9.23	52.36	3.55	6.23	43.80

Run No.	Stage 3 Mass (mb)[b]	Stage 3 D_{50} size (µmA)[c]	Stage 3 Cum. % less than[d]	Stage 4 Mass (mg)[b]	Stage 4 D_{50} size (µmA)[c]	Stage 4 Cum. % less than[d]	Stage 5 Mass (mg)[b]	Stage 5 D_{50} size (µmA)[c]	Stage 5 Cum. % less than[d]	Stage 6 Mass (mg)[b]	Stage 6 D_{50} size (µmA)[c]	Stage 6 Cum. % less than[d]
ESP-0-1-1(2)	7.16	3.59	13.64	6.21	2.28	7.20	3.97	1.10	3.08	1.22	0.65	1.81
ESP-0-1-2(2)	15.78	3.69	26.07	5.46	2.34	18.72	4.20	1.13	13.06	3.31	0.67	8.61
ESP-0-1-3	10.88	3.51	18.23	8.03	2.22	9.69	4.61	1.07	4.79	1.32	0.63	3.39
ESP-0-1-4	8.96	3.53	27.72	6.88	2.24	15.06	3.80	1.08	8.07	1.10	0.64	6.05
ESP-0-2-1	8.29	3.61	16.67	6.48	2.29	9.93	3.41	1.11	6.39	1.35	0.65	4.98
ESP-0-2-2	6.92	4.12	21.55	6.51	2.62	11.04	3.99	1.28	4.59	1.61	0.76	1.99
ESP-0-2-3	11.26	4.03	18.10	15.03	2.56	9.52	10.06	1.25	3.78	2.21	0.74	2.52
ESP-0-2-4	9.53	3.73	22.19	8.24	2.37	9.96	4.43	1.15	3.39	0.86	0.68	2.11
ESP-0-3-1	12.89	3.61	27.13	10.90	2.29	17.26	9.53	1.11	8.63	2.59	0.65	6.29
ESP-0-3-2	7.72	3.83	33.03	8.64	2.44	18.35	6.12	1.18	7.96	1.51	0.70	5.39
ESP-0-3-3	6.90	4.11	22.26	6.39	2.62	12.68	5.10	1.27	5.03	1.19	0.76	3.25
ESP-0-3-4	7.06	4.05	35.40	6.82	2.58	21.76	5.57	1.25	10.63	2.03	0.75	6.57
ESP-0-4-1	12.99	3.66	18.08	12.54	2.32	8.26	5.51	1.12	3.94	1.50	0.66	2.76
ESP-0-4-2	8.92	3.81	31.09	7.70	2.42	17.37	4.95	1.17	8.56	1.39	0.69	6.08
ESP-0-4-3	5.21	4.40	14.00	5.25	2.80	0.33	4.06	1.37	3.95	1.03	0.82	2.83
ESP-0-4-4(2)	4.71	4.23	32.45	6.85	2.69	15.94	5.06	1.31	3.74	1.40	0.78	0.36

(continued)

TABLE 4-8 (continued)

Run No.	Stage 7			Filter	
	Mass, (mb)[b]	D_{50} size (µmA)[c]	Cum. % less than[d]	Mass, (mg)[b]	D_{50} size (µmA)[c]
ESP-0-1-1(2)	0.83	0.41	0.95	0.92	< 0.41
ESP-0-1-2(2)	3.96	0.43	3.28	2.43	< 0.43
ESP-0-1-3	1.63	0.40	1.65	1.56	< 0.40
ESP-0-1-4	1.69	0.41	2.94	1.60	< 0.41
ESP-0-2-1	1.73	0.42	3.19	3.07	< 0.42
ESP-0-2-2	0.78	0.49	0.73	0.45	< 0.49
ESP-0-2-3	0.70	0.48	2.12	3.70	< 0.48
ESP-0-2-4	0.48	0.44	1.40	0.94	< 0.44
ESP-0-3-1	2.44	0.42	4.08	4.51	< 0.42
ESP-0-3-2	0.85	0.45	3.95	2.33	< 0.45
ESP-0-3-3	0.55	0.49	4.42	1.62	< 0.49
ESP-0-3-4	1.22	0.48	4.13	2.06	< 0.48
ESP-0-4-1	1.32	0.42	1.73	2.20	< 0.42
ESP-0-4-2	1.34	0.45	3.70	2.08	< 0.45
ESP-0-4-3	0.69	0.53	2.09	1.93	< 0.53
ESP-0-4-4(2)	0.15	0.51	0.00	0.00	< 0.51

[a] Data taken from Table 3-6, pages 61 and 62 of test report (Appendix B). Emissions from a coal-fired rotary kiln downstream of an ESP. Andersen impactor data.

[b] mg = net weight in milligrams.

[c] D_{50} size - cut-point of cyclone or impactor stage in micrometers (µmA - aerodynamic diameter).

[d] Cumulative percent less than or equal to stated size.

TABLE 4-9. SUMMARY OF TEST DATA FOR REFERENCE 45 - TRUCK LOADING DAY[a] (RUN S-1)
Data Rating: A

Sampler ID No.	Upwind (back-ground)	Downwind (source)	Sampling height (m)	Concentration of particulate matter measured by sampler ($\mu g/m^3$)[b]									
				Total particulate[d]	Total suspended particulate[e]	Inhalable particulate[f]	Cyclone/Impactor stages (μmA)[c]						
							> 11.36[g]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[h]
TSP-1	X		2	-	-	-	-	-	-	-	-	-	-
TSP-2		X	2.5	-	248,024	-	-	-	-	-	-	-	-
IP-3	X		2	-	-	-	-	-	-	-	-	-	-
IP-4		X	2.5	-	-	165,970	-	-	-	-	-	-	-
IP-5		X	4	-	-	365,468	-	-	-	-	-	-	-
CI-1	X		2	-	-	-	-	-	-	-	-	-	-
CI-2		X	2.5	495,333	-	-	342,001	49,808	63,540	23,721	10,201	3,971	2,009
CI-3		X	4	614,826	-	-	347,185	10,484	30,728	43,066	105,123	74,677	3,562

[a] Data taken from Table 3-11, page 84 of test report (Appendix B). Emissions from the loading of pulverized agricultural limestone into open trucks.

[b] $\mu g/m^3$ = micrograms of pollutant per cubic meter of gas sampled. - Indicates no data directly available.

[c] Based on cut-point of cyclone or impactor stages in micrometers aerodynamic diameter (μmA).

[d] Particles < ~ 300 μmA. Determined from total mass collected in cyclone/impactor.

[e] Particles < ~ 30 μmA. Determined from samples collected by standard hi-vol.

[f] Particles < 15 μmA. Determined from samples collected by hi-vol equipped with Andersen size-selective inlet.

[g] Cyclone catch.

[h] Backup filter.

TABLE 4-10. SUMMARY OF TEST DATA FOR REFERENCE 45 - TRUCK LOADING BAY (RUNS S-2)[a]
Data Rating: A

Sampler ID No.	Upwind (back-ground)	Downwind (source)	Sampling height (m)	Concentration of particulate matter measured by sampler ($\mu g/m^3$)[b] Total particulate[d]	Total suspended particulate[e]	Inhalable particulate[f]	Cyclone/Impactor stages (µmA)[c] > 11.36[g]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[h]
TSP-1	X		2	-	-	-	-	-	-	-	-	-	-
TSP-2		X	2.5	-	299,257	-	-	-	-	-	-	-	-
IP-3	X		2	-	-	-	-	-	-	-	-	-	-
IP-4		X	2.5	-	-	172,466	-	-	-	-	-	-	-
IP-5		X	4	-	-	351,464	-	-	-	-	-	-	-
CI-1	X		2	-	-	-	-	-	-	-	-	-	-
CI-2		X	2.5	232,775	-	-	108,572	32,829	46,490	22,680	15,196	4,324	2,682
CI-3		X	4	244,064	-	-	80,731	40,824	57,009	31,522	22,150	8,101	3,724

[a] Data taken from Table 3-12, page 85 of test report (Appendix B). Emissions from the loading of pulverized agricultural limestone into tanker-type trucks.

[b] $\mu g/m^3$ = micrograms of pollutant per cubic meter of gas sampled. - Indicates no data directly available.

[c] Based on cut-point of cyclone or impactor stages in micrometers aerodynamic diameter (µmA).

[d] Particles < ~ 300 µmA. Determined from total mass collected in cyclone/impactor.

[e] Particles < ~ 30 µmA. Determined from samples collected by standard hi-vol.

[f] Particles < 15 µmA. Determined from samples collected by hi-vol equipped with Andersen size-selective inlet.

[g] Cyclone catch.

[h] Backup filter.

TABLE 4-11. SUMMARY OF TEST DATA FOR REFERENCE 45 - TRUCK LOADING BAY (RUNS 5-3)[a]
Data Rating: A

Sampler ID No.	Upwind (background)	Downwind (source)	Sampling height (m)	Concentration of particulate matter measured by sampler (μg/m³)[b]									
				Total particulate[d]	Total suspended particulate[e]	Inhalable particulate[f]	Cyclone/Impactor stages (μmA)[c]						
							> 11.36[g]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[h]
TSP-1	X		2	-	-	-	-	-	-	-	-	-	-
TSP-2		X	2.5	-	107,508	-	-	-	-	-	-	-	-
IP-3	X		2	-	-	-	-	-	-	-	-	-	-
IP-4		X	2.5	-	-	70,710	-	-	-	-	-	-	-
IP-5		X	4	-	-	248,194	-	-	-	-	-	-	-
CI-1	X		2	-	-	-	-	-	-	-	-	-	-
CI-2		X	2.5	145,350	-	-	92,382	2,047	6,195	10,042	19,909	13,184	1,588
CI-3		X	4	359,993	-	-	244,245	4,606	13,519	26,069	43,701	25,698	2,153

[a] Data taken from Table 3-13, page 86 of test report (Appendix B). Emissions from the loading of pulverized agricultural limestone into tanker-type trucks.

[b] μg/m³ = micrograms of pollutant per cubic meter of gas sampled. - Indicates no data directly available.

[c] Based on cut-point of cyclone or impactor stages in micrometers aerodynamic diameter (μmA).

[d] Particles < ~ 300 μmA. Determined from total mass collected in cyclone/impactor.

[e] Particles < ~ 30 μmA. Determined from samples collected by standard hi-vol.

[f] Particles < 15 μmA. Determined from samples collected by hi-vol equipped with Andersen size-selective inlet.

[g] Cyclone catch.

[h] Backup filter.

TABLE 4-12. SUMMARY OF TEST DATA FOR REFERENCE 45 - TRUCK LOADING BAY (RUN S-4)[a]
Data Rating: A

Sampler ID No.	Upwind (background)	Downwind (source)	Sampling height (m)	Concentration of particulate matter measured by sampler ($\mu g/m^3$)[b]									
				Total particulate[d]	Total suspended particulate[e]	Inhalable particulate[f]	Cyclone/impactor stages (μmA)[c]						
							> 11.36[g]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[h]
TSP-1	X		2	-	625	-	-	-	-	-	-	-	-
TSP-2		X	2.5	-	86,186	-	-	-	-	-	-	-	-
IP-3	X		2	-	-	473	-	-	-	-	-	-	-
IP-4		X	2.5	-	-	125,341	-	-	-	-	-	-	-
IP-5		X	4	-	-	628,807	-	-	-	-	-	-	-
CI-1	X		2	369	-	-	e	e	e	e	e	e	e
CI-2		X	2.5	237,711	-	-	184,372	13,308	22,856	8,595	5,648	1,765	1,164
CI-3		X	4	586,912	-	-	93,824	17,208	52,508	90,438	194,503	132,692	5,736

a Data taken from Table 3-14, page 87 of test report (Appendix B). Emissions from the loading of pulverized agricultural limestone into tanker-type trucks.

b $\mu g/m^3$ = micrograms of pollutant per cubic meter of gas sampled. - Indicates no data directly available.

c Based on cut-point of cyclone or impactor stages in micrometers aerodynamic diameter (μmA).

d Particles < ~ 300 μmA. Determined from total mass collected in cyclone/impactor.

e Particles < ~ 30 μmA. Determined from samples collected by standard hi-vol.

f Particles < 15 μmA. Determined from samples collected by hi-vol equipped with Andersen size-selective inlet.

g Cyclone catch.

h Backup filter.

TABLE 4-13. SUMMARY OF TEST DATA FOR REFERENCE 45 - TRUCK LOADING BAY (RUN S-5)[a]
Data Rating: A

Sampler ID No.	Upwind (back-ground)	Downwind (source)	Sampling height (m)	Concentration of particulate matter measured by sampler (μg/m³)[b]									
				Total particulate[d]	Total suspended particulate[e]	Inhalable particulate[f]	Cyclone/Impactor stages (μmA)[c]						
							> 11.36[g]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[h]
TSP-1	X		2	-	273	-	-	-	-	-	-	-	-
TSP-2		X	2.5	-	8,681	-	-	-	-	-	-	-	-
IP-3	X		2	-	-	146	-	-	-	-	-	-	-
IP-4		X	2.5	-	-	5,545	-	-	-	-	-	-	-
IP-5		X	4	-	-	64,640	-	-	-	-	-	-	-
CI-1	X		2	423	-	-	260	5	16	22	32	44	42
CI-2		X	2.5	56,609	-	-	53,917	725	755	274	240	205	490
CI-3		X	4	59,439	-	-	46,172	4,363	3,206	1,343	653	39	3,461

[a] Data taken from Table 3-15, page 68 of test report (Appendix B). Emissions from the loading of glass lime into tanker-type trucks.

[b] μg/m³ = micrograms of pollutant per cubic meter of gas sampled. - Indicates no data directly available.

[c] Based on cut-point of cyclone or impactor stages in micrometers aerodynamic diameter (μmA).

[d] Particles < ~ 300 μmA. Determined from total mass collected in cyclone/impactor.

[e] Particles < ~ 30 μmA. Determined from samples collected by standard hi-vol.

[f] Particles < 15 μmA. Determined from samples collected by hi-vol equipped with Andersen size-selective inlet.

[g] Cyclone catch.

[h] Backup filter.

TABLE 4-14. SUMMARY OF EMISSION FACTORS FOR TOTAL PARTICULATE

Type of source	Control equipment	Ref. No.	No. of ~~tests~~ runs	Type of fuel	Average measured particulate emission factor[a] kg/Mg lime	Average measured particulate emission factor[a] lb/ton lime	Quality	Candidate particulate emission factor[b] kg/Mg lime	Candidate particulate emission factor[b] lb/ton lime	Emission factor rating
Rotary kilns	Uncontrolled	23	3	Coal	138.3	276.6	C	180	350	D
		24	3	Coal	166.1	332.2	B			
		45	4x4[c]	Coal	186.0	371.9	A			
	Large diameter cyclone	32	2	Coal	102.5	205.0	B	81	160	D
		45	4x4[c]	Coal	60.20	120.4	A			
	Multiclone	32	2	Coal	41.7	83.4	B	42	83	D
	ESP	12	3	Gas	0.14	0.28	B	2.4	4.8	D
		45	4x4[c]	Coal	4.7	9.3	A			
	Venturi scrubber	13	3	Coal	1.99	3.98	C	2.4[f]	4.8[f]	D
		23	3	Coal	1.166	2.332	B			
		26	3	Coal	4.086	8.172	C			
	Gravel bed filter	8 1	2	Unknown	0.56	1.1	C	0.53[g]	1.1[g]	E
		10	3	Gas	0.43	0.86	C			
		25	3	Coal	0.59	1.2	C			
	Multiclone and venturi scrubber	29	3	Coal and gas	0.437	0.874	B	0.44	0.87	D
	Baghouse	14 2	3	Coal	0.2807	0.5614	B	0.45[f]	0.89[f]	C
		17 3	1x6[d]	Coal	0.460	0.920	C			
		27	1x4x12[e]	Coal	0.468	0.936	D			
		28 5	6	Coal	0.0812	0.162	C			
		40	1x6[d]	Coal	0.4136	0.8272	B			
		41	3x1[h]	Coal	0.515[j]	1.03[j]	B			
		42	6[i]	Coal	0.913[j]	1.83[j]	C			
	Cyclone and baghouse	45	4x4[c]	Coal	0.055	0.11	A	0.055	0.11	D

(continued)

TABLE 4-14. (continued)

Type of source	Control equipment	Ref. No.	No. of tests	Type of fuel	Average measured particulate emission factor[a] kg/Mg lime	lb/ton lime	Quality	Candidate particulate emission factor[b] kg/Mg lime	lb/ton lime	Emission factor rating
Atmospheric hydrator	Medium energy wet scrubber	20 28	3 3	-- --	0.032 0.0447	0.064 0.0894	C B	0.045	0.089	D
Crusher, screen, hammermill[k]	Baghouse	21 4	3	--	0.0005	0.001	B	0.0005	0.001	D
Final screen[k]	Baghouse	21 4	3	--	0.0004	0.0008	B	0.0004	0.0008	D

[a] Average emission factor calculated from raw test data contained in reference document. See calculations in Appendix C.

[b] Arithmetic mean of average measured emission factors for A- and B-rated data sets shown in previous columns. Rounded to two significant figures (wherever possible).

[c] Four tests with four samples each.

[d] One test on each of six baghouse stacks.

[e] One test on four of 12 identical baghouse sections.

[f] Arithmetic mean of average measured emission factors for B- and C-rated data sets in previous column.

[g] Arithmetic mean of average measured emission factors for C-rated data sets in previous column.

[h] Three tests on one of six baghouse stacks.

[i] One test on each of two stacks of two baghouse collectors arranged in parallel (with existing bags). Remaining two tests are duplicate runs conducted on one stack of one baghouse equipped with new bags.

[j] Average emissions for baghouses equipped with new and old bags.

[k] Emission factors expressed as mass of pollutant per mass of limestone feed.

4.2.2 Particle Size Data

Each of the specific data sets discussed above were processed through the appropriate computer program as described in Section 3.0 to obtain both the particle size distribution and size-specific emission factors for selected particle diameters. Copies of the individual computer printouts have been included in Appendix D, with the results of the computer analyses summarized in Tables 4-15 through 4-22. Any calculations needed to convert the raw data to the proper format for input to the computer were conducted manually, and copies of such calculations are also included in Appendix D. In the case of Reference 45, the test results were already analyzed by the spline routine as part of the study and thus, no further data reduction was necessary. The tabular data presented in the test report were simply reproduced in Tables 4-18 to 4-22.

A number of notations should be made regarding the particle size data shown in Tables 4-15 through 4-22. First only data for particles larger than 2.5 μm (aerodynamic diameter) have been reported even though the spline routine was asked to predict values below that size range. This particular lower cut-off was selected since 2.5 μmA is the smallest particle diameter specified by the EPA. In addition, the size-specific emission factors calculated from the test data have also been reported in each table even though they may not actually be used in the development of the candidate emission factors for the process. In those cases where the emission factors were not used, the values have been included only for the sake of comparison.

4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTORS

4.3.1 Total Particulate Emission Factors

The most ideal situation for the development of candidate emission factors would be a large number of A-rated data sets from which to derive such. As discussed above, such was not available for this particular study. In the case of the uncontrolled emissions from rotary kilns, only three test series were found in the literature. By averaging the A- and B-rated data contained in these test series, an emission factor almost identical to that already contained in AP-42 was developed.

TABLE 4-15. CALCULATED PARTICLE SIZE DISTRIBUTIONS AND UNCONTROLLED EMISSION FACTORS FOR REFERENCE 24[a]

Data Rating: C

Test ID No.	Cumulative mass % equal to or less than stated size[b]					Cumulative emission factor equal to or less than stated size (kg/Mg)[c]					
	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total mass emission factor
1	2.77	3.25	4.16	7.96	14.3	5.64	6.60	8.45	16.2	29.0	203.2
2	2.16	2.51	3.66	7.50	13.8	3.19	3.71	5.40	11.1	20.4	147.6

a From computer printouts included in Appendix D. Uncontrolled coal-fired rotary kiln.

b Aerodynamic diameter.

c Kilograms of particulate matter per Mg (10^6 g) of lime produced.

TABLE 4-16. CALCULATED PARTICLE SIZE DISTRIBUTIONS FOR REFERENCE 29 - VENTURI SCRUBBER INLET[a]

Data Rating: C

Test ID No.	Cumulative mass % equal to or less than stated size[b] 2.5 μmA	5.0 μmA	10.0 μmA	15.0 μmA	20.0 μmA
1	2.35	4.01	12.1	21.6	30.8
2	1.22	3.13	6.12	11.4	18.7
3	1.66	3.11	6.30	11.8	19.2

[a] From computer printouts included in Appendix D. Measured downstream of a multiple cyclone dust collector.

[b] Aerodynamic diameter.

TABLE 4-17. CALCULATED PARTICLE SIZE DISTRIBUTIONS AND PARTICULATE EMISSION FACTORS FOR REFERENCE 32 - BAGHOUSE INLET[a]
Data Rating: C

Test ID No.	Cumulative mass % equal to or less than stated size[b]					Cumulative emission factor equal to or less than stated size (kg/Mg)[c]					
	2.5 μmA	5.0 μmA	10.0 μmA	15.0 μmA	20.0 μmA	2.5 μmA	5.0 μmA	10.0 μmA	15.0 μmA	20.0 μmA	Total mass emission factor
Kiln 4[d]	19.3	29.0	39.5	47.6	54.3	12.5	18.7	25.5	30.7	35.0	64.6
Kiln 6[e]	11.2	17.8	21.6	27.3	33.9	11.5	18.3	22.1	28.0	34.8	102.5

[a] From computer printouts included in Appendix D. Emissions from two separate coal-fired rotary kilns.

[b] Aerodynamic diameter.

[c] Kilograms of particulate matter per Mg (10^6 g) of lime produced.

[d] Measured at outlet of multiple cyclone collector.

[e] Measured at outlet of low efficiency cyclone collector.

TABLE 4-18. CALCULATED EMISSION FACTORS FOR REFERENCE 45 - KILN NO. 6 BAGHOUSE INLET[a]

Data Rating: A

Run No.	Total mass emission rate		Production rate[b]		Total mass emission factor[c]		Size-specific emission factors[c]					
							≤ 15 μmA[d]		≤ 10 μmA[d]		≤ 2.5 μmA[d]	
	(lb/hr)	(kg/hr)	(ton/day)	(Mg/day)	(lb/ton)	(kg/Mg)	(lb/ton)	(kg/Mg)	(lb/ton)	(kg/Mg)	(lb/ton)	(kg/Mg)
Bag-I-1-1	1,842	836.3	276	251	160.2	80.10	82.0	41.0	56.1	28.1	32.7	16.4
Bag-I-1-2	1,271	577.0	276	251	110.5	55.25	64.8	32.4	46.9	23.5	9.2	4.6
Bag-I-1-3	1,816	824.5	276	251	157.9	78.95	87.6	43.8	61.7	30.9	13.2	6.60
Bag-I-1-4	1,227	557.1	276	251	106.7	53.35	64.8	32.4	43.1	21.6	1.9	0.95
Average	1,539	698.7	276	251	133.8	66.90	74.8	37.4	52.0	26.0	14.2	7.10
Bag-I-2-1	1,473	668.7	276	251	128.1	64.05	73.5	36.8	53.3	26.7	16.6	8.30
Bag-I-2-2(2)[e]	1,336	606.5	276	251	116.1	58.05	116.5	58.25	117.1	58.55	94.1	47.1
Bag-I-2-3(2)	1,548	702.8	276	251	134.6	67.30	82.3	41.2	57.4	28.7	10.0	5.00
Bag-I-2-4	1,129	512.6	276	251	98.1	49.1	56.7	28.4	40.8	20.4	11.0	5.50
Average	1,383	627.9	276	251	120.3	60.15	70.8	35.4	50.5	25.3	12.5	6.25
Bag-I-3-1	1,634	741.8	276	251	142.1	71.05	88.3	44.2	64.1	32.1	17.5	8.75
Bag-I-3-2	1,503	682.4	276	251	130.7	65.35	83.3	41.7	65.3	32.7	29.5	14.8
Bag-I-3-3	1,539	698.7	276	251	133.8	66.90	78.6	39.3	57.3	28.7	11.3	5.65
Bag-I-3-4	779	354	276	251	67.7	33.9	40.7	20.4	27.8	13.9	4.1	2.1
Average	1,364	619.3	276	251	118.9	59.45	72.7	36.4	53.6	26.8	15.6	7.8
Bag-I-4-1	1,369	621.5	276	251	119.1	59.55	67.0	33.5	44.6	22.3	9.8	4.9
Bag-I-4-2	881	400	276	251	76.6	38.3	44.9	22.5	32.8	16.4	8.6	4.3
Bag-I-4-3	1,392	632.0	276	251	121.1	60.55	70.6	35.3	48.6	24.3	9.1	4.6
Bag-I-4-4	1,341	608.8	276	251	116.6	58.30	74.6	37.3	53.9	27.0	7.9	4.0
Average	1,246	565.7	276	251	108.4	54.20	64.3	32.2	45.0	22.5	8.9	4.5
Total average	1,383	627.9	276	251	120.4	60.2	70.7	35.4	50.3	25.2	12.8	6.40

[a] Reproduced from Table 3-5, page 47 of test report (Appendix B). Tests conducted at the outlet of a cyclone collector.

[b] Short tons (2,000 lb) of lime per day or Mg (10^6 g) of lime per day.

[c] Pounds of particulate matter per short ton (2,000 lb) of lime produced or kilogram of particulate matter per Mg (10^6 g) of lime produced.

[d] Aerodynamic diameter.

[e] Not used in calculations due to suspect loading of the impactor stages.

TABLE 4-19. CALCULATED EMISSION FACTORS FOR REFERENCE 45 - KILN NO. 6 BAGHOUSE OUTLET[a]

Data Rating: A

Run No.	Total mass emission rate (lb/hr)	Total mass emission rate (kg/hr)	Production rate[b] (ton/day)	Production rate[b] (Mg/day)	Total mass emission factor[c] (lb/ton)	Total mass emission factor[c] (kg/Mg)	Size-specific emission factors[c] ≤ 15 μmA[d] (lb/ton)	≤ 15 μmA[d] (kg/Mg)	≤ 10 μmA[d] (lb/ton)	≤ 10 μmA[d] (kg/Mg)	≤ 2.5 μmA[d] (lb/ton)	≤ 2.5 μmA[d] (kg/Mg)
Bag-0-1-1[e]	0.45	0.20	276	251	0.04	0.02	0.08	0.04	0.07	0.03	0.003	0.002
Bag-0-1-2[e]	2.0	0.91	276	251	0.18	0.090	0.15	0.075	0.13	0.065	0.05	0.03
Bag-0-1-3(2)[e]	1.25	0.68	276	251	0.11	0.055	0.06	0.03	0.05	0.03	0.01	0.005
Bag-0-1-4[e]	2.30	1.04	276	251	0.20	0.10	0.18	0.090	0.15	0.075	0.06	0.03
Average	1.50	0.681	276	251	0.13	0.065	0.09	0.05	0.08	0.04	0.03	0.02
Bag-0-2-1	0.85	0.39	276	251	0.08	0.04	0.06	0.03	0.05	0.03	0.02	0.01
Bag-0-2-2	0.75	0.34	276	251	0.07	0.04	0.06	0.03	0.05	0.03	0.02	0.01
Bag-0-2-3	1.05	0.77	276	251	0.09	0.05	0.02	0.01	0.01	0.005	0.006	0.003
Bag-0-2-4	1.50	0.681	276	251	0.13	0.065	0.11	0.055	0.09	0.05	0.04	0.02
Average	1.05	0.77	276	251	0.09	0.05	0.06	0.03	0.05	0.03	0.02	0.01
Bag-0-3-1	1.05	0.77	276	251	0.09	0.05	0.09	0.05	0.07	0.04	0.03	0.015
Bag-0-3-2	1.65	0.49	276	251	0.15	0.075	0.14	0.070	0.14	0.070	0.05	0.03
Bag-0-3-3	1.05	0.77	276	251	0.09	0.05	0.01	0.005	0.01	0.005	0.006	0.003
Bag-0-3-4	1.00	0.454	276	251	0.09	0.05	0.06	0.03	0.06	0.03	0.03	0.02
Average	1.20	0.545	276	251	0.10	0.050	0.08	0.04	0.07	0.04	0.03	0.02
Bag-0-4-1	0.60	0.27	276	251	0.05	0.03	0.04	0.02	0.04	0.02	0.02	0.01
Bag-0-4-2	1.55	0.704	276	251	0.14	0.070	0.13	0.065	0.10	0.050	0.04	0.02
Bag-0-4-3	0.75	0.35	276	251	0.07	0.04	0.06	0.03	0.05	0.03	0.03	0.02
Bag-0-4-4	1.60	0.26	276	251	0.14	0.070	0.11	0.055	0.09	0.05	0.03	0.02
Average	1.15	0.522	276	251	0.10	0.050	0.09	0.05	0.07	0.04	0.03	0.02
Arithmetic mean ($\bar{x}$)					0.11	0.055	0.08	0.04	0.06	0.03	0.03	0.02
Geometric mean (x_g)					0.0984	0.0520	0.0690	0.0347	0.0580	0.0307	0.0212	0.0119
Standard deviation (σ)					0.0454	0.0213	0.0480	0.0241	0.0419	0.0207	0.0171	0.00982
Standard geometric deviation (σ_g)					1.55	1.51	2.13	2.14	2.22	2.22	2.39	2.45

[a] Reproduced from Table 3-5, page 48 of test report (Appendix B). Tests conducted at the outlet of a baghouse collector.

[b] Short tons (2,000 lb) of lime per day or Mg (10^6 g) of lime per day.

[c] Pounds of particulate matter per short ton (2,000 lb) of lime produced or kilogram of particulate matter per Mg (10^6 g) of lime produced.

[d] Aerodynamic diameter.

[e] Not used in calculations due to suspect loading of the impactor stages.

TABLE 4-20. CALCULATED FACTORS FOR REFERENCE 45 - KILN NO. 7 ELECTROSTATIC PRECIPITATOR INLET[a]

Data Rating: A

Run No.	Total mass emission rate[b]		Production rate[c]		Total mass emission factor[d]		Size-specific emission factors[d]					
							≤ 15 μmA[e]		≤ 10 μmA[e]		≤ 2.5 μmA	
	(lb/hr)	(kg/hr)	(ton/day)	(Mg/day)	(lb/ton)	(kg/Mg)	(lb/ton)	(kg/Mg)	(lb/ton)	(kg/Mg)	(lb/ton)	(kg/Mg)
ESP-I-1-1	2,687.0	1,213.0	300	272	215.0	107.5	82.7	41.4	32.1	16.1	2.7	1.4
ESP-I-1-2	3,677.5	1,670.0	300	272	294.2	147.1	110.4	55.20	41.5	20.8	3.3	1.7
ESP-I-1-3	3,962.7	1,799.1	300	272	317.0	158.5	121.1	60.55	46.4	23.2	4.0	2.0
ESP-I-1-4	7,391.7	3,355.8	300	272	591.4	295.7	222.0	111.0	80.1	40.1	4.5	2.3
Average	4,429.7	2,011.1	300	272	354.4	177.2	134.0	67.00	50.0	25.0	3.6	1.8
ESP-I-2-1	3,853.3	1,749.4	300	272	308.3	154.2	144.5	72.25	73.2	36.6	2.9	1.5
ESP-I-2-2	4,491.3	2,039.1	300	272	359.3	179.7	359.3	180.0	59.7	29.9	4.8	2.4
ESP-I-2-3	5,875.9	2,667.7	300	272	470.1	235.1	181.7	90.85	70.0	35.0	5.1	2.6
ESP-I-2-4	4,697.3	2,132.6	300	272	375.8	187.9	162.6	81.30	73.3	36.7	3.0	1.5
Average	4,729.4	2,147.1	300	272	378.4	189.2	212.0	106.0	69.1	34.6	4.0	2.0
ESP-I-3-1	3,824.5	1,736.3	300	272	306.0	153.0	119.4	59.70	45.9	23.0	2.4	1.2
ESP-I-3-2	5,163.9	2,344.4	300	272	413.1	206.6	165.1	82.55	68.0	34.0	3.1	1.6
ESP-I-3-3	5,880.3	2,670.0	300	272	470.4	235.2	181.3	90.65	68.5	34.3	2.4	1.2
ESP-I-3-4	4,904.5	2,226.6	300	272	392.4	196.2	150.6	75.30	56.3	28.2	2.5	1.3
Average	4,943.3	2,244.3	300	272	395.5	197.8	154.1	77.05	59.7	29.9	2.6	1.3
ESP-I-4-1	4,670.0	2,120.2	300	272	373.6	186.8	147.4	73.70	58.6	29.3	3.7	1.9
ESP-I-4-2	4,688.6	2,128.7	300	272	375.1	187.6	134.2	67.10	49.0	24.5	1.9	0.95
ESP-I-4-3	3,711.7	1,685.1	300	272	296.9	148.5	117.2	58.60	46.5	23.3	1.8	0.90
ESP-I-4-4	4,903.4	2,226.1	300	272	392.3	196.2	153.2	76.60	61.6	30.8	4.0	2.0
Average	4,493.4	2,040.0	300	272	359.5	179.8	138.0	69.00	53.9	27.0	2.8	2.4
Total average	4,649.0	2,110.7	300	272	371.9	186.0	159.5	79.75	58.2	29.1	3.3	1.7

[a] Reproduced from Table 3-7, page 63 of test report (Appendix B). Tests conducted at the outlet of a coal-fired rotary kiln.

[b] Mass emission rate for entire kiln in pounds of particulate matter per hour or kilograms of particulate matter per hour.

[c] Short tons (2,000 lb) of lime per day or Mg (10^6 g) of lime per day.

[d] Pounds of particulate matter per short ton (2,000 lb) of lime produced or kilogram of particulate matter per Mg (10^6 g) of lime produced.

[e] Aerodynamic diameter.

TABLE 4-21. CALCULATED EMISSION FACTORS FOR REFERENCE 45 - KILN NO. 7 ELECTROSTATIC PRECIPITATOR OUTLET[a]

Data Rating: A

Run No.	Total mass emission rate[b] (lb/hr)	Total mass emission rate[b] (kg/hr)	Production rate[c] (ton/day)	Production rate[c] (Mg/day)	Total mass emission factor[d] (lb/ton)	Total mass emission factor[d] (kg/Mg)	Size-specific emission factors[d] ≤ 15 μmA[e] (lb/ton)	≤ 15 μmA[e] (kg/Mg)	≤ 10 μmA[e] (lb/ton)	≤ 10 μmA[e] (kg/Mg)	≤ 2.5 μmA (lb/ton)	≤ 2.5 μmA (kg/Mg)
ESP-0-1-1(2)	58.6	26.6	300	272	4.7	2.4	2.1	1.1	1.5	0.75	0.4	0.2
ESP-0-1-2(2)	53.4	24.2	300	272	4.3	2.2	3.8	1.9	2.5	1.3	0.8	0.4
ESP-0-1-3	161.2	73.18	300	272	12.9	6.45	8.0	4.0	6.3	3.2	1.5	0.75
ESP-0-1-4	132.9	60.34	300	272	10.6	5.30	9.0	4.5	6.7	3.4	1.9	0.95
Average	101.5	46.08	300	272	8.1	4.1	5.7	2.9	4.3	2.2	1.1	0.55
ESP-0-2-1	73.1	33.2	300	272	5.9	3.0	3.8	1.9	2.1	1.1	0.6	0.3
ESP-0-2-2	87.2	39.6	300	272	7.0	3.5	4.0	2.0	3.3	1.7	0.7	0.4
ESP-0-2-3	87.2	39.6	300	272	10.8	5.40	3.8	1.9	3.6	1.8	1.0	0.50
ESP-0-2-4	135.3	61.43	300	272	18.2	9.10	11.4	5.70	9.6	4.8	2.0	1.0
Average	27.0	12.3	300	272	10.5	5.25	5.8	2.9	4.7	2.4	1.1	0.55
ESP-0-3-1	110.2	50.03	300	272	8.8	4.4	7.0	4.5	4.7	2.4	1.7	0.85
ESP-0-3-2	90.0	40.9	300	272	7.2	3.6	6.2	3.1	4.3	2.2	1.4	0.70
ESP-0-3-3	120.5	54.71	300	272	9.7	4.9	4.6	2.3	4.2	2.1	1.2	0.60
ESP-0-3-4	131.2	59.57	300	272	10.5	5.25	6.9	3.5	6.4	3.2	2.2	1.1
Average	113.0	51.30	300	272	9.1	4.6	6.2	3.1	4.9	2.5	1.6	0.80
ESP-0-4-1	125.6	57.02	300	272	10.0	5.00	5.8	2.9	4.5	2.3	1.0	0.50
ESP-0-4-2	143.0	64.92	300	272	11.5	5.75	9.1	4.6	7.8	3.9	2.1	1.1
ESP-0-4-3	117.6	53.39	300	272	9.4	4.7	2.5	1.3	2.4	1.2	0.7	0.4
ESP-0-4-4	86.8	39.4	300	272	6.9	3.5	3.7	1.9	3.7	1.9	1.0	0.50
Average	118.3	53.71	300	272	9.5	4.8	5.3	2.7	4.6	2.3	1.2	0.60
Total average	115.9	52.62	300	272	9.3	4.7	5.8	2.9	4.6	2.3	1.3	0.65

[a] Reproduced from Table 3-7, page 64 of test report (Appendix B). Tests conducted at the outlet of an ESP.

[b] Mass emission rate of all three ESP modules in pounds of particulate matter per hour or kilograms of particulate matter per hour.

[c] Short tons (2,000 lb) of lime per day or Mg (10^6 g) of lime per day.

[d] Pounds of particulate matter per short ton (2,000 lb) of lime produced or kilogram of particulate matter per Mg (10^6 g) of lime produced.

[e] Aerodynamic diameter.

TABLE 4-22. CALCULATED EMISSION FACTORS FOR REFERENCE 45 - TRUCK LOADING BAY[a]

Data Rating: A

Run No.	Type of truck	Type of material loaded	Silt content (%)[c]	Average air velocity through loading area (ft/sec)	Average air velocity through loading area (m/sec)	Size-specific emission factors[b] Total particulate[d] (lb/ton)	Total particulate[d] (kg/Mg)	Inhalable particulate[e] (lb/ton)	Inhalable particulate[e] (kg/Mg)	Fine particulate[f] (lb/ton)	Fine particulate[f] (kg/Mg)
S-1	Open	Limestone[g]	40.1	580.4	176.9	1.676	0.838	0.896	0.448	0.166	0.083
S-2	Enclosed	Limestone[g]	40.1	580.4	176.9	0.714	0.357	0.636	0.318	0.084	0.042
S-3	Enclosed	Limestone[g]	40.1	608.3	185.4	0.816	0.408	0.508	0.254	0.088	0.044
S-4	Open	Limestone[g]	40.1	608.3	185.4	1.332	0.666	1.144	0.572	0.352	0.176
S-5	Enclosed	Glasslime	29.6	400.0	121.9	0.302	0.151	0.124	0.062	0.016	0.008

Note: Overall emission factor = f(% silt, wind velocity, and type of truck loaded).

a Reproduced from Table 3-18, page 102 of test report (Appendix B). Tests conducted of the uncontrolled fugitive emissions generated during truck loading operations.

b Pounds of particulate matter per short ton (2,000 lb) of product loaded or kilograms of particulate matter per Mg (10^6 g) of product loaded.

c Percent less than 74 μm (physical diameter).

d Particles $\leq \sim 300$ μmA.

e Particles ≤ 15 μmA.

f Particles ≤ 2.5 μmA.

g Pulverized limestone.

For the sake of traceability, it is recommended that the factor developed in the current study be substituted for that which appears in Section 8.15 of AP-42 (as shown in Table 4-23).

For uncontrolled product coolers, only one test series consisting of three runs was found during the literature search. As noted previously, these data were of poor quality and thus eliminated from consideration. In addition, it could not be determined from the background document for Section 8.15 of AP-42 where the data used to develop the existing emission factor originated from. For these reasons, no change is proposed for the existing emission factor for product coolers pending further investigation.

In the case of controlled emissions, the data based developed during the program is somewhat more extensive. Not all of these data are of the highest quality, however, with some categories having only one test from which to develop a candidate emission factor. Controlled emission factors were developed for rotary kilns, atmospheric hydrators, limestone crushers/screens/hammermills, and limestone final screens by taking an arithmetic mean of the highest quality data sets available as shown previously in Table 4-14. The various factors thus obtained are summarized in Table 4-23 as proposed for inclusion into AP-42. It should be noted from Table 4-23, that the controlled emission factor for atmospheric hydrators agree with that already presented in Table 8.15-1 of AP-42.

4.3.2. Size-Specific Particulate Emission Factors

As indicated previously, only limited particle size data are available for the emissions from lime plants consisting of a total of nine tests representing 5 separate kilns and one product loading operation. For rotary kilns, two test series were collected during the study for uncontrolled kilns, kilns with large diameter cyclones, and kilns with multiclones. Only one test series was available for kilns with ESPs and kilns with baghouses. The final data set gathered as part of the literature search consisted of five individual tests of the fugitive emissions associated with the loading of limestone and lime into open-bed and tanker-type trucks.

TABLE 4-23. SUMMARY OF CANDIDATE PARTICULATE EMISSION FACTORS FOR TOTAL MASS[a]

Type of source	Type of control technology	Candidate total mass emission factor[b] lb/ton lime	kg/Mg lime	Emission factor rating
Rotary kilns[c]	Uncontrolled	350	180	D
	Large diameter cyclone	160	81	D
	Multiclone	83	42	D
	Electrostatic precipitator[d]	4.8	2.4	D
	Venturi scrubber	4.8	2.4	D
	Gravel bed filter[d]	1.1	0.53	E
	Multiclone and venturi[d] scrubber	0.87	0.44	D
	Baghouse	0.89	0.45	C
	Cyclone and baghouse	0.11	0.055	D
Atmospheric hydrator	Medium energy wet scrubber	0.089	0.045	D
Crusher, screen, and hammermill[e]	Baghouse	0.01	0.0005	D
Final screen[e]	Baghouse	0.0008	0.0004	D
Truck loading[f]:				
limestone (open trucks)	Uncontrolled	1.5	0.75	D
limestone (closed trucks)	Uncontrolled	0.76	0.38	D
lime (closed trucks)	Uncontrolled	0.30	0.15	E

[a] Data taken from Table 4-14 of this report.

[b] Emission factor proposed for inclusion into AP-42 expressed as either pounds of particulate matter per short ton (2,000 lb) of lime produced or kilograms of particulate matter per metric ton (mg = 10^6 g) of lime produced.

[c] Coal-fired kilns.

[d] Coal/natural-gas fired kilns.

[e] Emission factors expressed as mass of pollutant per mass of limestone feed.

[f] Data taken from Tables 3-18 and 3-19 of Reference No. 45.

According to OAQPS guidelines, A- and B-rated data should not be combined with C- or D-rated data to develop emission factors for a particular source. However, in the case of uncontrolled rotary kilns and rotary kilns equipped with cyclones it was found necessary to combine A-rated data with C-rated data in order to improve the overall applicability of the emission factors. This was deemed appropriate since it was felt that the inclusion of the C data would significantly enhance the overall usefulness of the emission factor to a larger cross section of the industry as a whole, and would not decrease the overall rating of the resultant emission factor.

To derive each emission factor, all of the data contained in Tables 4-15 through 4-22 were tabulated according to the type of process and control equipment, and the arithmetic mean and standard deviation calculated wherever possible for each particle size increment. The arithmetic mean was calculated from the data in each column according to the relationship:

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i \qquad (4\text{-}1)$$

where: $\bar{x}$ = arithmetic mean

n = number of measurements

x_i = individual measurements

The standard deviation was calculated according to the relationship:

$$\sigma = \left[\frac{\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{n}}{n-1} \right]^{1/2} \qquad (4\text{-}2)$$

where: σ - standard deviation with x_i and n as defined in Equation (4-1)

The geometric mean and standard deviation were also calculated, with the standard geometric deviation being indicative of the overall variance in the data. The geometric mean was calculated from the data in each column according to the relationship:

$$\bar{x}g = \exp \frac{1}{n} \sum_{i=1}^{n} \ln x_i \tag{4-3}$$

where: $\bar{x}_g$ = geometric mean with x_i and n as defined in Equation (4-1)

The standard geometric deviation was calculated according to the relationship:

$$\sigma_g = \exp \left[\sum_{i=1}^{n} \frac{\ln x_i - \overline{\ln x}^{\,2}}{n-1} \right]^{1/2} \tag{4-4}$$

where: σ_g = standard geometric deviation with x_i and n as defined in Equation (4-1)

Rather than utilizing the emission factors actually derived from each individual study, the candidate emission factor for each size increment was obtained by applying the average particle size distribution from the various data sets to the total particulate emission factor shown in Table 4-23 of this category report. This approach was used to take advantage of the generally more extensive data base which exists for total mass emissions. It was felt that this approach would produce emission factors more representative of the total industry. The results of such analysis are shown in Tables 4-24 through 4-27.

In the case of rotary kilns controlled by a cyclone followed by baghouse collector, only one test series (Reference 45) was available which included both the total mass emissions from the baghouse as well as the particle size distribution. In this instance, the above statistics have been included in Table 4-19 and thus were not been presented again. The reader is directed to that table for the size specific emission factors for kilns equipped with a cyclone/baghouse combination.

TABLE 4-24. CANDIDATE SIZE - SPECIFIC EMISSION FACTORS FOR UNCONTROLLED ROTARY KILNS

Emission Factor Rating: D

Ref. No.	Data quality rating	Summary data table No.[a]	Test ID No.	Cumulative mass % equal to or less than stated size[b]				Cumulative emission factor equal to or less than stated size (kg/Mg)[c]				Total mass emission factor (kg/Mg)
				2.5μmA	5.0μmA	10.0μmA	15.0μmA	2.5μmA	5.0μmA	10.0μmA	15.0μmA	
24	C	4-15	1	2.8	3.3	4.2	8.0	5.0	5.9	7.6	14	180
			2	2.2	2.5	3.7	7.5	4.0	4.5	6.7	14	180
45	A	4-20	ESP-I-1[d]	1.0	--	14	38	1.8	--	25	68	180
			ESP-I-2[d]	1.1	--	18	56	2.0	--	32	100	180
			ESP-I-3[d]	0.66	--	15	40	1.2	--	27	72	180
			ESP-I-4[d]	0.78	--	15	38	1.4	--	27	68	180
Arithmetic mean ($\bar{x}$)				1.4	2.9	12	31	2.6	5.2	21	56	--
Geometric mean (x_g)				1.2	2.9	9.8	24	2.2	5.2	18	43	--
Standard deviation (σ)				0.87	0.57	6.1	19	1.6	0.99	11	35	--
Standard geometric deviation (σ_g)				1.8	1.2	2.0	2.4	1.8	1.2	2.0	2.4	--

[a] Table in this report from which reduced data was taken.

[b] Aerodynamic diameter. Percentages rounded to two significant figures.

[c] Based on total mass emission factor of 180 kg of particulate matter per metric ton (Mg) of lime produced from Table 4-23 of this report.

[d] Average of four tests. Percentages back-calculated from emission factors originally presented in test report.

TABLE 4-25. CANDIDATE SIZE - SPECIFIC EMISSION FACTORS FOR ROTARY KILNS CONTROLLED BY CYCLONES
Emission Factor Rating: D

Ref. No.	Data quality rating	Summary data table No.[a]	Test ID No.	Cumulative mass % equal to or less than stated size[b] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	Cumulative emission factor equal to or less than stated size (kg/Mg)[c] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	Total mass emission factor (kg/Mg)
32	C	4-17	Kiln 6	11	18	22	27	8.9	15	18	22	81
45	A	4-18	Bag-1-1[d]	11	--	39	56	8.9	--	32	45	81
			Bag-1-2[d]	10	--	42	59	8.1	--	34	48	81
			Bag-1-3[d]	13	--	45	61	11	--	37	49	
			Bag-1-4[d]	8.2	--	42	59	6.6	--	34	48	81
Arithmetic mean ($\bar{x}$)				11	18	38	52	8.7	15	31	42	--
Geometric mean (x_g)				11	--	37	50	8.6	--	30	41	--
Standard deviation (σ)				1.7	--	9.2	14	1.6	--	7.5	12	--
Standard geometric deviation (σ_g)				1.2	--	1.3	1.4	1.2	--	1.3	1.4	--

a Table in this report from which reduced data was taken.

b Aerodynamic diameter. Percentages rounded to two significant figures.

c Based on total mass emission factor of 81 kg of particulate matter per metric ton (Mg) of lime produced from Table 4-23 of this report.

d Average of four tests. Percentages back-calculated from emission factors originally presented in test report.

TABLE 4-26. CANDIDATE SIZE - SPECIFIC EMISSION FACTORS FOR ROTARY KILNS CONTROLLED BY MULTICLONES

Emission Factor Rating: E

Ref. No.	Data quality Rating	Summary data table No.[a]	Test ID No.	Cumulative mass % equal to or less than stated size[b] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Cumulative emission factor equal to or less than stated size (kg/Mg)[c] 2.5 µmA	5.0 µmA	10.0 µmA	15.0 µmA	20.0 µmA	Total mass emission factor (kg/Mg)
29	C	4-16	1	2.4	4.0	12.1	22	31	1.01	1.7	5.1	9.2	13	42
			2	1.2	3.1	6.1	11	19	0.50	1.3	2.6	4.6	8.0	42
			3	1.7	3.1	6.3	12	19	0.71	1.3	2.7	5.0	8.0	42
32	C	4-17	Kiln 4	19	29	40	48	54	8.0	12	17	20	23	42
Arithmetic mean ($\bar{x}$)				6.1	9.8	16	23	31	2.6	4.1	6.9	9.7	13	--
Geometric mean (x_g)				3.1	5.8	12	19	28	1.3	2.4	5.0	8.1	12	--
Standard deviation (σ)				8.6	13	16	17	17	3.6	5.3	6.9	7.2	7.1	--
Standard geometric deviation (σ_g)				3.5	3.0	2.4	2.0	1.6	3.5	2.9	2.4	2.0	1.7	--

[a] Table in this report from which reduced data was taken.

[b] Aerodynamic diameter. Percentages rounded to two significant figures.

[c] Based on total mass emission factor of 42 kg of particulate matter per metric ton (Mg) of lime produced from Table 4-23 of this report.

TABLE 4-27. CANDIDATE SIZE - SPECIFIC EMISSION FACTORS FOR ROTARY KILNS CONTROLLED BY ELECTROSTATIC PRECIPITATORS

Emission Factor Rating: D

Ref. No.	Data quality rating	Summary data table No.[a]	Test ID No.	Cumulative mass % equal to or less than stated size[b]			Cumulative emission factor equal to or less than stated size (kg/Mg)[c]			Total mass emission factor (kg/Mg)
				2.5 μmA	10.0 μmA	15.0 μmA	2.5 μmA	10.0 μmA	15.0 μmA	
45	A	4-21	ESP-O-1[d]	14	53	70	0.34	1.3	1.7	2.4
			ESP-O-2[d]	11	45	55	0.26	1.1	1.3	2.4
			ESP-O-3[d]	18	54	68	0.43	1.3	1.6	2.4
			ESP-O-4[d]	13	48	56	0.31	1.2	1.3	2.4
Arithmetic mean ($\bar{x}$)				14	50	62	0.34	1.2	1.5	--
Geometric mean (x_g)				14	50	62	0.33	1.2	1.5	--
Standard deviation (σ)				2.9	4.2	7.8	0.071	0.096	0.21	--
Standard geometric deviation (σ_g)				1.2	1.1	1.1	1.2	1.1	1.2	--

[a] Table in this report from which reduced data was taken.

[b] Aerodynamic diameter. Percentages rounded to two significant figures.

[c] Based on total mass emission factor of 2.4 kg of particulate matter per metric ton (Mg) of lime produced from Table 4-23 of this report.

[d] Average of four tests. Percentages back-calculated from emission factors originally presented in test report.

Several factors should be noted from MRI's analysis of the test data. The first item of note is the wide variation in the particle size distribution from one data set to another for the same type of source and control equipment. In some cases, the percentage of the total mass emissions for any particular size increment can vary up to an order of magnitude from one test series to another. This is evidenced by the fairly large standard deviations (arithmetic and geometric) calculated for these data.

Another factor worthy of note is the size distribution and associated emission factors calculated for kilns with cyclones as compared to those equipped with multiclones. From available test data, it was determined that the percent of small particles (e.g., 2.5 to 10 µmA) actually dropped for kilns equipped with multiclones as compared to those with single cyclones. This trend is also reflected in the resulting emission factors which show higher emissions for particles in the smaller size ranges for kilns with single cyclones versus those equipped with multiclones. Such a trend would not be expected since the size-efficiency relationship for multiclones is such that only finer particles (i.e., < 15-20 µmA) should penetrate the collector resulting in a larger mass fraction of the total emissions in the smaller particle size ranges. An explanation for these anomalous data was not obvious from a review of the various test reports. Therefore, it is recommended that the candidate size-specific emission factors for kilns equipped with cyclones not be included in AP-42 at the present time pending further data collection and analysis.

A summary of the candidate size specific emission factors for both rotary kilns and truck loading operations are shown in Tables 4-28 and 4-29, respectively, and graphically in Figures 4-1 and 4-2.

4.4 EMISSION FACTOR QUALITY RATING

The quality of the average emission factors contained in Tables 4-28 and 4-29 were rated according to the criteria specified in Section 3.0 of this report. In most cases, higher quality particle size data was applied to a lower quality emission factor (i.e., D-rated). The resultant emission factor was therefore assigned the same rating as that of the factor for total mass emission from which it was derived.

TABLE 4-28. SUMMARY OF CANDIDATE SIZE-SPECIFIC EMISSION FACTORS FOR ROTARY LIME KILNS[a]
Emission Factor Rating: D

Particle size (µmA)	Cumulative mass % equal to or less than stated particle size[b]: Uncontrolled rotary kilns[d]	Rotary kiln with multiclone[e]	Rotary kiln with ESP[f]	Rotary kiln with cyclone and baghouse[g]	Cumulative particulate emission factor equal to or less than stated size[c]: Uncontrolled rotary kilns[d] lb/ton	Uncontrolled rotary kilns[d] kg/Mg	Rotary kiln with multiclone[e] lb/ton	Rotary kiln with multiclone[e] kg/Mg	Rotary kiln with ESP[f] lb/ton	Rotary kiln with ESP[f] kg/Mg	Rotary kiln with cyclone and baghouse[g] lb/ton	Rotary kiln with cyclone and baghouse[g] kg/Mg
2.5	1.4	6.1	14	27	5.2	2.6	5.2	2.6	0.68	0.34	0.03	0.02
5.0	2.9	9.8	-	-	10	5.2	8.2	4.1	-	-	-	-
10.0	12	16	50	55	42	21	14	6.9	2.4	1.2	0.06	0.03
15.0	31	23	62	73	110	56	19	9.7	3.0	1.5	0.08	0.04
20.0	-	31	-	-	-	-	26	13	-	-	-	-
Total mass emission factor[h]					350	180	83	42	4.8	2.4	0.11	0.055

[a] Coal-fired rotary kilns.

[b] Aerodynamic diameter. All percentages rounded to two significant figures.

[c] Unit weight of particular matter per unit weight of lime produced. Rounded to two significant figures.

[d] From Table 4-24 of this report.

[e] Emission factor rating = E. See Table 4-26.

[f] ESP = electrostatic precipitator. From Table 4-27 of this report. Coal/natural gas-fired kilns.

[g] From Table 4-19 of this report. Percentages back-calculated from emission factors presented in Reference 45. Rotary kiln equipped with a cyclone collector followed by a baghouse.

[h] From Table 4-23 of this report.

TABLE 4-29. CANDIDATE FUGITIVE EMISSION FACTORS FOR PRODUCT LOADING (UNCONTROLLED)[a]

Type of loading operation	Average particulate emission factors[b]: Total particulate[c] (kg/Mg)	Total particulate[c] (lb/ton)	Inhalable particulate[d] (kg/Mg)	Inhalable particulate[d] (lb/ton)	Fine particulate[e] (kg/Mg)	Fine particulate[e] (lb/ton)	Emission factor rating
Loading of pulverized limestone into open-bed trucks	0.75	1.5	0.51	1.0	0.13	0.26	D
Loading of pulverized limestone into tanker-type trucks	0.38	0.76	0.29	0.58	0.043	0.086	D
Loading of glass lime into tanker-type trucks[f]	0.15	0.30	0.062	0.12	0.0080	0.016	E

[a] Reproduced from Table 3-19, page 109 of Reference 45.

[b] Mass of pollutant per mass of product loaded. Rounded to two significant figures.

[c] Particles < ~ 300 μmA (aerodynamic diameter).

[d] Particles < 15 μmA (aerodynamic diameter).

[e] Particles < 2.5 μmA (aerodynamic diameter).

[f] From Table 3-18, page 102 of Reference 41.

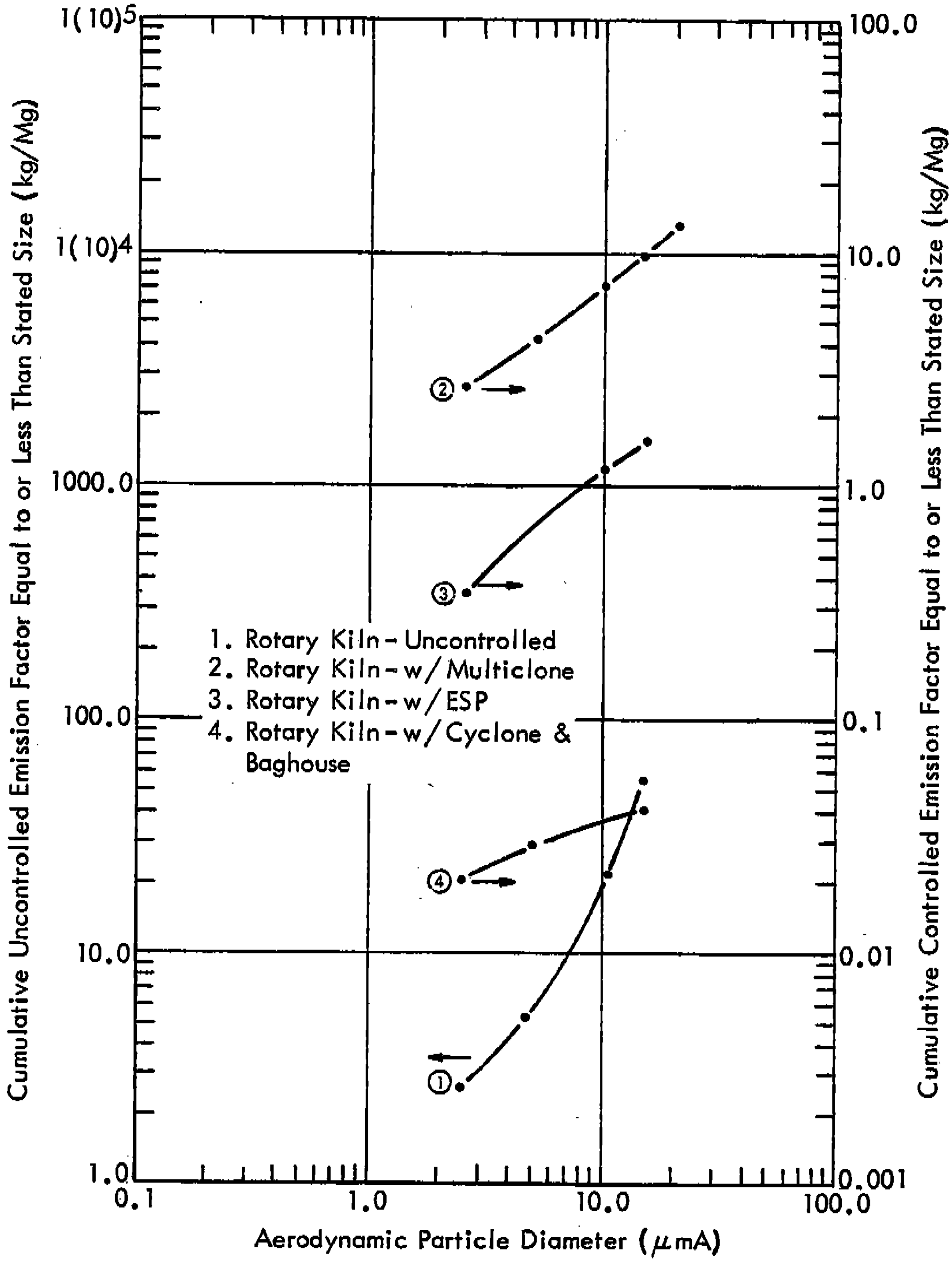

Figure 4-1. Size specific emission factors for lime kilns.

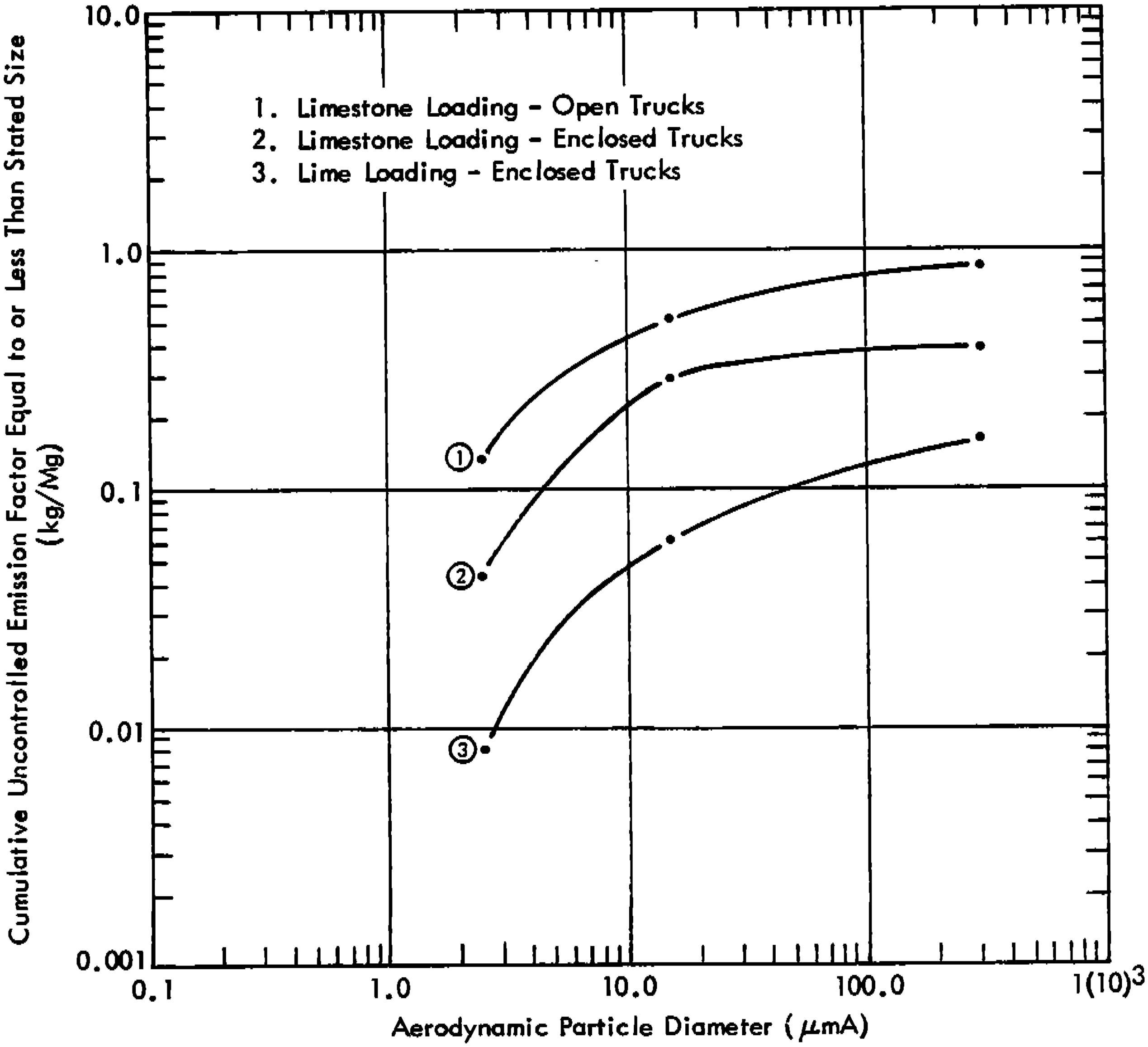

Figure 4-2. Size-specific emission factors for product loading.

For rotary kilns equipped with multiclones, C-rated particle size data was applied to a D-rated total mass emission factor. Due to the extremely poor quality of the data available, a rating of E was assigned to the emission factor for this source category using the criteria specified by the OAQPS. Thus, caution should be exercised when applying this particular emission factor.

REFERENCES FOR SECTION 4.0

1. Collins, T. T., Jr., "Pilot Plant Study of a Multiclone Unit Operating on Stack Gases from a Lime Kiln," Paper Trade Journal, 126(12):63-64, March 18, 1948.

*2. Lewis, C. J., and B. B. Crocker, "The Lime Industry's Problem of Airborne Dust," JAPCA, 19(1):31-39, January 1969.

3. Air Pollutant Emission Factors, EPA Contract No. CPA-22-69-119, Resources Research, Inc., Reston, VA, April 1970.

*4. Vandegrift, A. E., et al., Particulate Pollutant System Study, Volume III: Handbook of Emission Properties, EPA Report APTD 0743 (NTIS PB 203128), U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1971.

*5. Shannon, L. J., et al., Particulate Pollutant System Study, Volume II: Fine Particle Emissions, EPA Report APTD 0744 (NTIS PB 203521), U. S. Environmental Protection Agency, Research Triangle Park, NC, August 1971.

6. DeHaven, L. B., et al., Source Test of Warner Co., Bellefonte, PA, Stack Test No. 1771, Commonwealth of Pennsylvania, Air Pollution Control, November 1971.

7. Kimura, G., et al., Report on the Emissions to the Atmosphere from a Lime Kiln Baghouse, Marblehead Lime Co., Chicago, IL, City of Chicago, Department of Environmental Control, Chicago, IL, July 1972.

8. Rovang, R. D., Trip Report, Paul Lime Company, Douglas, AZ, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, January 1973.

9. Results of Particulate Emission Tests, Basic Magnesia, Inc., Port St. Joe, FL, Environmental Science and Engineering, Inc., Gainesville, FL, June 1973.

10. Maurice, R. L., and P. F. Allard, Stack Emissions on No. 5 Kiln, Paul Lime Plant, Inc., Engineers Testing Laboratories, Inc., Phoenix, AZ, June 1973.

11. Particulate Emission Test Efficiency Evaluation, Allied Products Corporation, Alabaster, AL, Alabama Air Pollution Control Commission, Field Services Section, Montgomery, AL, May 1974.

12. Air Pollution Emission Test, Dow Chemical, Freeport, TX, Project Report No. 74-LIM-6, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, May 1974.

13. Schoch, J. B., Exhaust Gas Emission Study, J. E. Baker Company, Millersville, OH, George D. Clayton and Associates, Southfield, MI, June 1974.

14. Eggleston, T. E., Air Pollution Emission Test, Bethlehem Mines Corporation, Annville, PA, EMB Test No. 74-LIM-1, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, August 1974.

15. Feairheller, W. R. and D. L. Harris, Particulate, Sulfur Dioxide, and Nitrogen Oxides Emission Measurements from Lime Plants, Woodville, OH, EMB Project Report No. 75-LIM-8, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, August 1974.

16. Emission Testing Report, Woodville Lime and Chemical Company, Woodville, OH, Report No. 74-LIM-3A, EPA Contract No. 68-02-0237, Task Order No. 26, (U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards), PEDCO - Environmental Specialists, Inc., Cincinnati, OH, 1974.

17. Air Pollution Emission Test, Marblehead Lime Company, Gary, Indiana, Report No. 74-LIM-7, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 1974.

18. Screening Study for Emissions Characterization from Lime Manufacture, EPA Contract No. 68-02-0299, Vulcan-Cincinnati, Inc., Cincinnati, OH, August 1974.

19. DeWees, W. G. and R. W. Gerstle, Air Pollution Emission Test, Woodville Lime and Chemical Company, Woodville, OH, Report No. 74-LIM-3B, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1974.

20. Air Pollution Emission Test, U.S. Lime Division, Flintkote Company, City of Industry, CA, Report No. 74-LIM-5, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, October 1974.

21. Air Pollution Emission Test, J. M. Brenner Company, Lancaster, PA, EPA Project No. 75-STN-7, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, November 1974.

22. Snowden, W. D., Atmospheric Emission Evaluation, U. S. Lime, Henderson, NV, Test No. 74-LIM-4, EPA Contract No. 68-02-0236, Valentine, Fisher, and Tomlinson, Inc., Seattle, WA, December 1974.

23. Stack Sampling Report of Official Air Pollution Emission Tests Conducted on Kiln No. 1 at J. E. Baker Company, Millersville, OH, Princeton Chemical Research, Inc., Princeton, NJ, March 1975.

24. Feairheller, W. R., and T. L. Peltier, Air Pollution Emission Test, Virginia Lime Company, Ripplemead, Virginia, EPA Contract No. 68-02-1404, Task 11, (EPA, Office of Air Quality Planning and Standards), Monsanto Research Corporation, Dayton, OH, April/May 1975.

25. Maurice, R. L. and P. F. Allard, Stack Emissions Analysis, U. S. Lime Plant, Nelson, AZ, Engineers Testing Laboratories, Inc., Phoenix, AZ, May 1975.

26. Stack Sampling Report of Official Air Pollution Emission Tests Conducted on Kiln No. 2 Scrubber at J. E. Baker Company, Millersville, OH, Princeton Chemical Research, Inc., Princeton, NJ, May 1975.

27. Crowell, D., et al., Test Conducted at Marblehead Lime Company, Bellefonte, PA, Report on the Particulate Emissions from a Lime Kiln Baghouse, Marblehead Lime Company, Chicago, IL, July 1975.

28. Peltier, T. L., Air Pollution Emission Test, Martin-Marietta Corporation, Calera, AL, EMB Project No. 76-LIM-9, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1975.

*29. Peltier, T.A., et al., Air Pollution Emission Test, Allied Products Company, Montevallo, Alabama, EPA Contract No. 68-02-1404, Task 20, (EPA, Office of Air Quality Planning and Standards), Monsanto Research Corporation, Dayton, OH, September 1975.

30. Fleming, R., and M. H. Erlich, Jr., Stack Sampling Report of Official Air Pollution Emission Test Conducted on Kiln No. 2 Scrubber at J. E. Baker Company, Millersville, OH, Princeton Chemical Research, Inc., Princeton, NJ, October 1975.

31. Baladi, E., Air Pollution Emission Test, Beker Industries, Inc., Coda, ID, EMB Report No. 75-PRP-4, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, November 1975.

*32. Feairheller, W. R., et al., Source Test of a Lime Plant, Standard Lime Company, Woodville, Ohio, EPA Contract No. 68-02-1404, Task 12, (EPA, Office of Air Quality Planning and Standards), Monsanto Research Corporation, Dayton, OH, December 1975.

33. Reid, R. J., Environmental Impact Statement for Lime Plants, EPA Contract No. 68-02-1324, Task 33, (EPA, Office of Air Quality Planning and Standards), Midwest Research Institute, Kansas City, MO, May 1976.

34. Air Pollution Emission Test, Kilns 1 and 2, J. E. Baker Company, Millersville, OH, EMB Project No. 76-LIM-11, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, August 1976.

35. Air Pollution Emission Test, Kilns 4, 5, and 6, Martin-Marietta Chemical Corporation, Woodville, OH, EMB Report No. 76-LIM-12, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, August 1976.

*36. Doumas, A. C., et al., Industrial Process Profiles for Environmental Use, Chapter 18, The Lime Industry, EPA-600/2-77-023r (NTIS PB281485), U. S. Environmental Protection Agency, Cincinnati, OH, February 1977.

37. Nevada Testing Laboratories, Report of Determinations Stack Emission Investigation Test Nos. 10 and 11 (Exhibit 4 supplied by the National Lime Association), February 1977.

38. Goodwin, D. R., Standards Support and Environmental Impact Statement, Volume I: Proposed Standards of Performance for Lime Manufacturing Plants, EPA-450/2-77-007a (NTIS PB 266942), U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1977.

39. Baladi, E., Air Pollution Emission Test, Flintkote Company, Blue Diamond, NE, EMB Project No. 76-NMM-3, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, April 1977.

40. Report on the Particulate Emissions from a Lime Kiln Baghouse (Exhibit 2 supplied by the National Lime Association), May 1977.

41. Report on the Particulate Emissions from a Lime Kiln Baghouse (Exhibit 3 supplied by the National Lime Association), May 1977.

42. Report on the Particulate Emissions from a Lime Kiln Baghouse (Exhibit 1 supplied by the National Lime Association), August 1977.

43. Goodwin, D.R., Final Standards Support and Environmental Impact Statement, Volume II: Promulgated Standards of Performance for Lime Manufacturing Plants, EPA-450/2-77-007b (NTIS PB80-194491, U. S. Environmental Protection Agency, Research Triangle Park, NC, October 1977.

44. Record, F. and W. T. Harnett, Particulate Emission Factors for the Construction Aggregate Industry, EPA Contract No. 68-02-3510, Work Assignment No. 27, GCA/Technology Division, Chapel Hill, NC, February 1983.

45. Cobb, G. R., et al., Characterization of Inhalable Particulate Matter Emissions from a Lime Plant, Vol. I EPA-600/X-85-342a, Midwest Research Institute, Kansas City, MO, May 1983.

*46. An Investigation of Particulate Emissions from Construction Aggregate Crushing Operations and Related New Source Performance Standards, National Crushed Stone Association, Washington, D.C., December 1979.

47. Stenger, J. B., and R. A. Bajura, Deposition of Aerosols in Sampling Probes, DOE Contract No. De-AT21-79MC11284-TO-38, West Virginia University, Morgantown, WV, May 1982.

*Indicates those documents which contain particle size data.

SECTION 5.0

PROPOSED AP-42 SECTION

The proposed revision to Section 8.15 of AP-42 is presented in the following pages as it would appear in the actual document.

8.15 LIME MANUFACTURING

8.15.1 General[1-4]

Lime is the high temperature product of the calcination of limestone. There are two kinds, high calcium lime (CaO) and dolomitic lime ($CaO \cdot MgO$). Lime is manufactured in various kinds of kilns by one of the following reactions:

$$CaCO_3 + \text{heat} \rightarrow CO_2 + CaO \text{ (high calcium lime)}$$
$$CaCO_3 \cdot MgCO_3 + \text{heat} \rightarrow CO_2 + CaO \cdot MgO \text{ (dolomitic lime)}$$

In some lime plants, the resulting lime is reacted (slaked) with water to form hydrated lime.

The basic processes in the production of lime are 1) quarrying raw limestone; 2) preparing limestone for the kilns by crushing and sizing; 3) calcining limestone; 4) processing the lime further by hydrating; and 5) miscellaneous transfer, storage and handling operations. A generalized material flow diagram for a lime manufacturing plant is given in Figure 8.15-1. 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 kiln feed 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 shaped kiln with a slowly revolving donut 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.

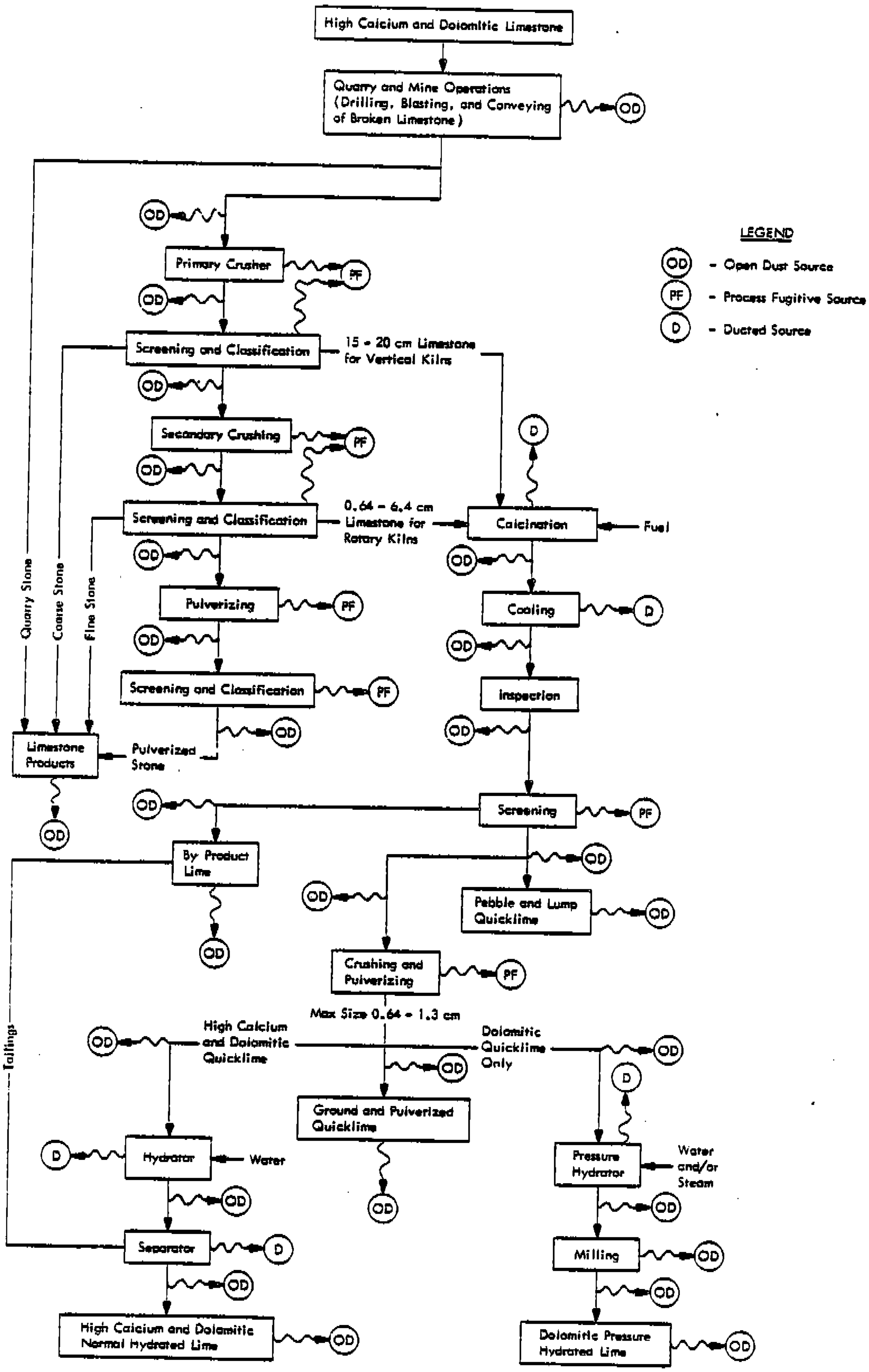

Figure 8.15-1. Simplified flow diagram for lime and limestone products.

About 10 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 normal 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, to prevent product loss. Following hydration, the product may be milled and then conveyed to air separators for further drying and removal of coarse fractions.

In the United States, lime plays a major role in chemical and metallurgical operations. Two of the largest uses are as steel flux and in alkali production. Lesser uses include construction, refractory and agricultural applications.

8.15.2 Emissions And Controls[3 5]

Potential air pollutant emission points in lime manufacturing plants are shown in Figure 8.15-1. Except for gaseous pollutants emitted from kilns, particulate is the only pollutant of concern from most of the operations.

The largest ducted source of particulate is the kiln. Of the various kiln types, fluidized beds have the most uncontrolled particulate emissions, because of the very small feed size 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 particulate emissions, also because of the small feed size and relatively high air velocities and 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 and the relatively low air velocities and slow movement of material through the kiln.

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

Nitrogen oxides, carbon monoxide and sulfur oxides are all produced in kilns, although the last are the only gaseous pollutant emitted in significant quantities. Not all of the sulfur in the kiln fuel is emitted as sulfur oxides, since some fraction reacts with the materials in the kiln. Some sulfur oxide reduction is also effected by the various equipment used for secondary particulate control.

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 away from the venting of product cooler exhaust, however, to maximize fuel use efficiencies. Cyclones, baghouses and wet scrubbers have been employed on coolers for particulate control.

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 8.20 and 11.2 of this document.

Controlled and uncontrolled emission factors and particle size data for lime manufacturing are given in Tables 8.15-1 through 8.15-3. The size distributions of particulate emissions from controlled and uncontrolled rotary kilns and uncontrolled product loading operations are shown in Figures 8.15-2 and 8.15-3.

TABLE 8.15-1. EMISSION FACTORS FOR LIME MANUFACTURING[a]

EMISSION FACTOR RATING: B

Source	Particulate[b] kg/Mg	Particulate[b] lb/ton	Nitrogen oxides kg/Mg	Nitrogen oxides lb/ton	Carbon monoxide kg/Mg	Carbon monoxide lb/ton	Sulfur dioxide kg/Mg	Sulfur dioxide lb/ton
Crushers, screens, conveyors, storage piles, unpaved roads, etc.	c	c	Neg	Neg	Neg	Neg	Neg	Neg
Rotary kilns[d]								
Uncontrolled[e]	180	350	1.4	2.8	1	2	f	f
Large diameter cyclone	81	160	1.4	2.8	1	2	f	f
Multiple cyclone	42	83	1.4	2.8	1	2	f	f
Electrostatic precipitator[g]	2.4	4.8	1.4	2.8	1	2	h	h
Venturi scrubber	2.4	4.8	1.4	2.8	1	2	h	h
Gravel bed filter[g]	0.53[i]	1.1[i]	1.4	2.8	1	2	h	h
Multiclone and venturi scrubber[g]	0.44	0.87	1.4	2.8	1	2	h	h
Baghouse	0.45[j]	0.89[j]	1.4	2.8	1	2	h	h
Cyclone and baghouse	0.055	0.11	1.4	2.8	1	2	h	h
Vertical kilns								
Uncontrolled	4	8	NA	NA	NA	NA	NA	NA
Calcimatic kilns[k]								
Uncontrolled	25	50	0.1	0.2	NA	NA	NA	NA
Multiple cyclone	3	6	0.1	0.2	NA	NA	NA	NA
Secondary dust collection[ℓ]	NA	NA	0.1	0.2	NA	NA	NA	NA
Fluidized bed kilns	m	m	NA	NA	NA	NA	NA	NA
Product coolers								
Uncontrolled	20[n]	40[n]	Neg	Neg	Neg	Neg	Neg	Neg
Hydrators (atmospheric)[p]								
Wet scrubber	0.05	0.1	Neg	Neg	Neg	Neg	Neg	Neg
Crusher, screen, hammermill								
Baghouse	0.0005	0.001	Neg	Neg	Neg	Neg	Neg	Neg
Final screen								
Baghouse	0.0004	0.0008	Neg	Neg	Neg	Neg	Neg	Neg
Uncontrolled truck loading								
Limestone								
Open truck	0.75	1.5	Neg	Neg	Neg	Neg	Neg	Neg
Closed truck	0.38	0.76	Neg	Neg	Neg	Neg	Neg	Neg
Lime - closed truck	0.15[i]	0.30[i]	Neg	Neg	Neg	Neg	Neg	Neg

TABLE 8.15-1 (cont.)

[a]References 4-7. Factors for kilns and coolers are per unit of lime produced. Divide by two to obtain factors per unit of limestone feed to the kiln. Factors for hydrators are per unit of hydrated lime produced. Multiply by 1.25 to obtain factors per unit of lime feed to the hydrator. Neg = negligible. NA = not available.
[b]Emission Factor Rating = D.
[c]Factors for these operations are presented in Sections 8.20 and 11.2 of this document.
[d]For coal fired rotary kilns only.
[e]No particulate control except for settling that may occur in stack breeching and chimney base.
[f]Sulfur dioxide may be estimated by a material balance using fuel sulfur content.
[g]Combination coal/gas-fired rotary kilns only.
[h]When scrubbers are used, < 5% of the fuel sulfur will be emitted as SO_2 even with high sulfur coal. When other secondary collection devices are used, about 20% of the fuel sulfur will be emitted as SO_2 with high sulfur fuels, and < 10% with low sulfur fuels.
[i]Emission Factor Rating = E.
[j]Emission Factor Rating = C.
[k]Calcimatic kilns generally have stone preheaters. Factors are for emissions after the kiln exhaust passes through a preheater.
[l]Fabric filters and venturi scrubbers have been used on calcimatic kilns. No data are available on particulate emissions after secondary control.
[m]Fluidized bed kilns must have sophisticated dust collection equipment for process economics, hence particulate emissions will depend on efficiency of the control equipment installed.
[n]Some or all cooler exhaust typically is used in kiln as combustion air. Emissions will result only from that fraction not recycled to kiln.
[p]Typical particulate loading for atmospheric hydrators following water sprays or wet scrubbers. Limited data suggest particulate emissions from pressure hydrators may be approximately 1 kg/Mg (2 lb/ton) of hydrate produced, after wet collectors.

TABLE 8.15-2. SUMMARY OF SIZE SPECIFIC EMISSION FACTORS FOR ROTARY LIME KILNS[a]

EMISSION FACTOR RATING: D

Particle size (μmA)	Cumulative mass % ≤ stated particle size[b]				Cumulative particulate emission factor ≤ stated size[c]							
	Uncontrolled rotary kiln	Rotary kiln with multiclone[d]	Rotary kiln with ESP[e]	Rotary kiln with cyclone and baghouse[f]	Uncontrolled rotary kilns		Rotary kiln with multiclone[d]		Rotary kiln with ESP[e]		Rotary kiln with cyclone and baghouse[f]	
					kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton
2.5	1.4	6.1	14	27	2.6	5.2	2.6	5.2	0.34	0.68	0.02	0.03
5.0	2.9	9.8	NA	NA	5.2	10	4.1	8.2	NA	NA	NA	NA
10.0	12	16	50	55	21	42	6.9	14	1.2	2.4	0.03	0.06
15.0	31	23	62	73	56	110	9.7	19	1.5	3.0	0.04	0.08
Total mass emission factor[g]					180	350	42	83	2.4	4.8	0.055	0.11

[a]Reference 7. Coal-fired rotary kilns. Numbers rounded to two significant figures. ESP = electrostatic precipitator.
NA = not available.
[b]Aerodynamic diameter.
[c]Unit weight of particulate matter/unit weight of lime produced.
[d]Emission Factor Rating = E.
[e]For combination coal/natural gas fired rotary kilns.
[f]For rotary kiln with cyclone collector followed by baghouse.
[g]PM_{10} emission factor data is not available for baghouse, venturi scrubber, simple cyclone and other control technologies used for rotary lime kilns.

TABLE 8.15-3. UNCONTROLLED FUGITIVE PARTICULATE EMISSION FACTORS FOR PRODUCT LOADING[a]

Type of loading operation	Total particulate[b]		Inhalable particulate[c]		Fine particulate[d]		Emission factor rating
	kg/Mg	lb/ton	kg/Mg	lb/ton	kg/Mg	lb/ton	
Pulverized limestone into open bed trucks	0.75	1.5	0.51	1.0	0.13	0.26	D
Pulverized limestone into tank trucks	0.38	0.76	0.29	0.58	0.043	0.086	D
Glass lime into tank trucks	0.15	0.30	0.062	0.12	0.0080	0.016	E

[a]Reference 7. Factors are for mass of pollutant/mass of product loaded. Numbers rounded to two significant figures.
[b]Particles < ~ 300 µmA (aerodynamic diameter).
[c]Particles < 15 µmA (aerodynamic diameter).
[d]Particles < 2.5 µmA (aerodynamic diameter).

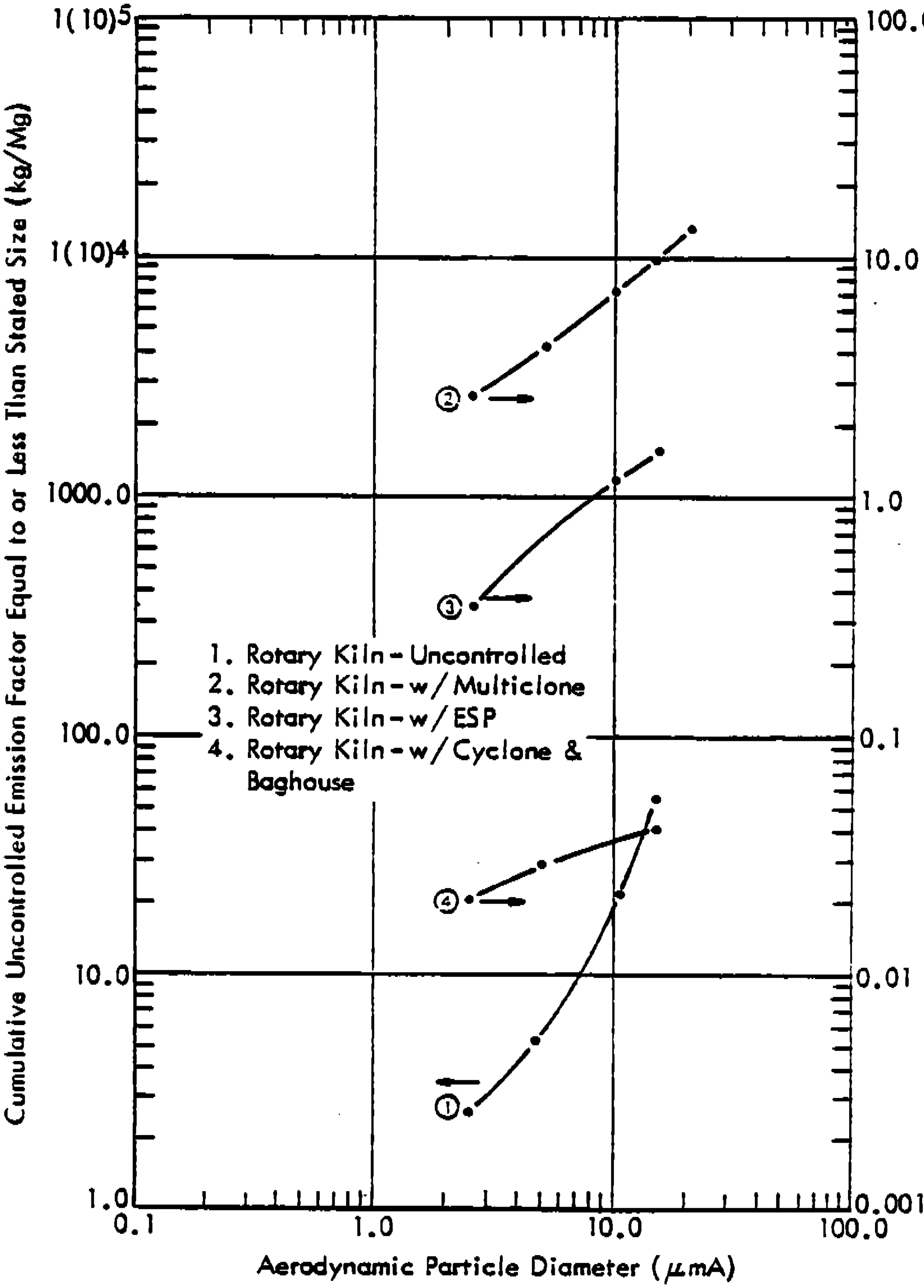

Figure 8.15-2. Size specific emission factors for lime kilns.

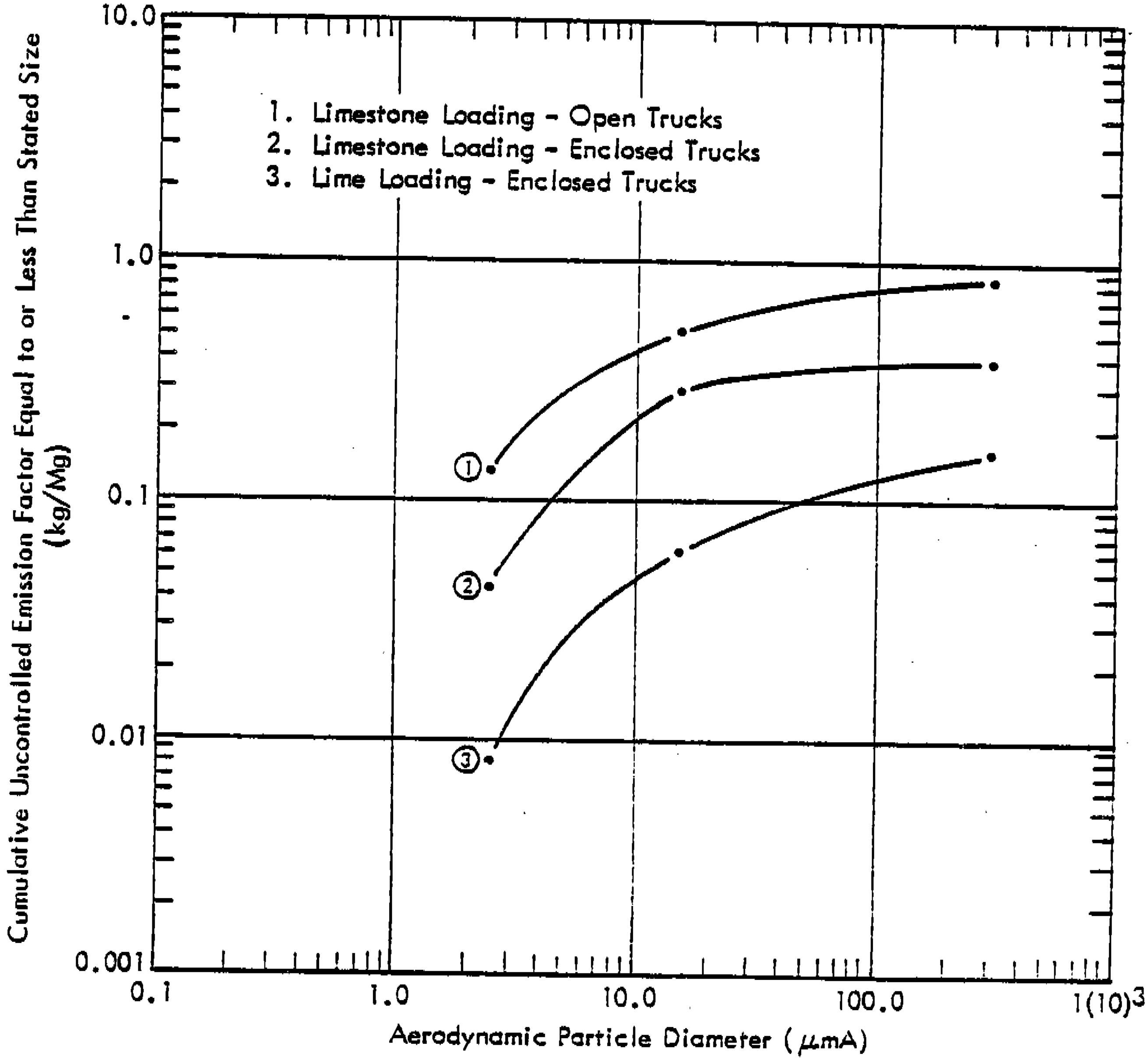

Figure 8.15-3. Size specific emission factors for product loading.

References for Section 8.15

1. C. J. Lewis and B. B. Crocker, "The Lime Industry's Problem of Airborne Dust", Journal of the Air Pollution Control Association, 19(1):31-39, January 1969.

2. Kirk-Othmer Encyclopedia of Chemical Technology, 2nd Ed., John Wiley and Sons, New York, 1967.

3. Screening Study for Emissions Characterization from Lime Manufacture, EPA Contract No. 68-02-0299. Vulcan-Cincinnati, Inc., Cincinnati, OH, August 1974.

4. Standards Support and Environmental Impact Statement, Volume 1: Proposed Standards of Performance for Lime Manufacturing Plants, EPA-450/2-77-007a, U. S. Environmental Protection Agency, Research Triangle Park, NC, April 1977.

5. Source test data on lime plants, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, 1976.

6. Air Pollutant Emission Factors, HEW Contract No. CPA 22-69-119, TRW Systems Group, Reston, VA, April 1970.

7. J. S. Kinsey, Lime and Cement Industry Particulate Emissions: Source Category Report; Volume I. Lime Industry, EPA Contract No. 68-02-3999, Midwest Research Institute, Kansas City, MO, August 1986.

APPENDIX A

COMPLETE LISTINGS OF JSKPRG AND JSKRAW

```
2 REM ----- PROGRAM "JSKPRG" -----
10 CLEAR 4000
12 REM ----- CLEAR REGISTERS FOR NEW RUN -----
15 OG=LOG(10):I2=0:XX=0:XD=0:X2=0:YP=0:ST=0:NZ=0:XM=0:LX=0:S1=0:YL=0:YM=0:DM=0:L1
=0:L2=0:L3=0:L4=0:L5=0
16 L6=0:K1=0:K2=0:K3=0:K4=0:K5=0:K6=0:JY=0:J9=0:IT=0:IJ=0:IM=0:I1=0
17 K2=0:I3=0:TL=0:KS=0:BA=0:SA=0:IQ=0:IX=0:I2=0:JX=0:IA=0:IC=0:IB=0
20 DIM XN(10),YO(10),X(53),A(16),B(4),CO(50,3),Y1(53),XD(15),XQ(10,50),YQ(10,50),
Y2(10),ID$(50),JX(50),JY(50),QQ(10,50),JQ(10),JW(10)
30 PRINT"PROGRAM SPLIN2 FROM FORTRAN ORIGINAL 02/22/82 V1"
31 LPRINT TAB(6); " ":LPRINT " ":LPRINT " ":LPRINT "                                SPLIN2
PROGRAM -  02/22/82 V1":LPRINT" ":LPRINT " "
39 REM ----- NUMBER OF DATA SETS AND REQUESTED OUTPUT -----
40 INPUT"ENTER # OF DATA SETS";QW
45 PRINT"ENTER D50'S IN INCREASING SIZE"
50 INPUT"ENTER NUMBER OF POINTS";NF
52 REM ----- INPUT PRODUCTION, EMISSION DATA -----
55 FOR QV=1 TO QW
58 INPUT"SET ID=";ID$(QV):INPUT "PROCESS WGT. RATE (TONS PRODUCED/HR)";JX(QV):INP
UT"TP EMISSION RATE (LB/HR)";JY(QV)
59 INPUT"ENTER PARTICLE DENSITY (g/cc)";JQ(QV):JW(QV)=SQR(JQ(QV))
60 FOR I=1 TO NF
70 INPUT"ENTER D50, CUM LOADING FOR EACH POINT";QQ(I,QV),YQ(I,QV):XQ(I,QV)=JW(QV)
*QQ(I,QV):NEXT I
80 PRINT"SET #";QV:NEXT QV
81 INPUT"ENTER # OF D50'S TO BE DETERMINED FOR ALL SETS";LA
82 FOR I=1 TO LA:INPUT"ENTER AERODYNAMIC D50";XD(I):NEXT I
83 FOR QV=1 TO QW:FOR I=1 TO NF:XN(I)=XQ(I,QV):YO(I)=YQ(I,QV):NEXT I
84 PRINT TIME$:LPRINT TAB(6);"TEST ID:  ";ID$(QV):LPRINT " ":LPRINT TAB(6);"INPUT
 DATA:        PROCESS WEIGHT RATE =";JX(QV);" TONS PROD./HR":LPRINT TAB(24);"TOTAL
 PARTICULATE EMISSION RATE =";JY(QV);" LB/HR":LPRINT TAB(24);"PARTICLE DENSITY ="
;JQ(QV);" G/CC"
85 LPRINT " ":LPRINT TAB(6);"MEASURED SIZE DISTRIBUTION":LPRINT " "
86 LPRINT TAB(6); "CUT(um)          CUM. % < CUT":LPRINT " "
88 FOR I=1 TO NF:LPRINT TAB(6); QQ(I,QV),"          ";YO(I):NEXT I:LPRINT" ":LPRINT
" "
89 NN=8:RR=NN:N=4:R=N
90 NP=((NF-2)*N)+NN+1
91 JE=JY(QV)/JX(QV)
92 LPRINT " ":LPRINT TAB(6);"OUTPUT DATA:    TP EMISSION FACTOR = ";JE; " LB/T  (
 ";0.5*JE;" KG/MT)":LPRINT" ":LPRINT " ":LPRINTTAB(41);"EMISSION FACTOR"
93 LPRINT TAB(6);"CUT (umA)     CUM. % < CUT       (LB/T)        (KG/MT)":LPRINT "
"
95 REM ----- SPLINE FIT OF MEASURED SIZE DISTRIBUTION -----
96 REM ----- BASIC TRANSLATION OF "SPLIN2" V1 02/22/82 -----
100 N2=NF-2
110 FOR I=1 TO N2
120 JJ=N-1
130 IF N2-I<0 THEN 150
140 JJ=N+2
150 M=(I-1)*N+1
160 X(M)=LOG(XN(I))/OG
170 Y1(M)=LOG(YO(I))/OG
180 XI=(LOG(XN(I+1))/OG-LOG(XN(I))/OG)/R
190 FOR II=1 TO 3
200 MM=I-1+II
210 B(II)=LOG(YO(MM))/OG
220 K=3*(II-1)
230 FOR J=1 TO 3
240 M3=I-1+J
250 A(K+J)=(LOG(XN(M3))/OG)[(II-1)
```

```
290 FOR J=1 TO 2
300 SL=B(2)+2*B(3)*LOG(XN(I+J-1))/OG
310 IF SL>=0 THEN 350
320 B(2)=(LOG(YO(I+1)/YO(I)))/OG/(LOG(XN(I+1)/XN(I))/OG):B(1)=LOG(YO(I))/OG-B(2)*
LOG(XN(I))/OG
330 B(3)=0:J=2
350 NEXT J
360 FOR J=1 TO JJ
370 K=M+J
380 X(K)=LOG(XN(I))/OG+J*XI
390 Y1(K)=B(1)+B(2)*X(K)+B(3)*X(K)[2
400 NEXT J:NEXT I
410 FOR I=1 TO 3
420 K=3*(I-1)
430 FOR J=1 TO 3
440 M=1+(J-1)*N
450 A(K+J)=X(M)[(I-1)
460 NEXT J:NEXT I
470 FOR I=1 TO 3
480 M=1+(I-1)*N:B(I)=Y1(M):NEXT I
490 KS=0
500 GOSUB 5000
510 SL=B(2)+2*B(3)*X(1)
520 IF SL>=0 THEN 600
530 FOR I=1 TO 3:A(I)=1:NEXT I
540 A(4)=X(1)-(X(N+1)-X(1))
550 A(7)=A(4)[2
560 FOR I=1 TO 2:K=3*I:FOR J=2 TO 3
570 M=1+((J-2)*N):A(K+J)=X(M)[I:NEXT J:NEXT I
580 B(1)=Y1(1)
590 FOR I=2 TO 3:M=1+((I-2)*N):B(I)=Y1(M):NEXT I
595 KS=0:GOSUB 5000
600 FOR I=1 TO 3
610 CO(1,I)=B(I):NEXT I
615 II=1
620 IN=NP-NN-1
630 FOR I=II TO IN
640 JJ=I:B(1)=0
650 FOR J=2 TO 3
660 K=I-1
670 IF I=1 THEN K=I
680 B(1)=B(1)+(J-1)*(CO(K,J))*X(I)[(J-2)
690 NEXT J
700 B(2)=CO(K,1)
720 FOR J=2 TO 3:LET B(2)=B(2)+CO(K,J)*X(I)[(J-1):NEXT J
730 B(3)=Y1(I+2)
740 FOR J=1 TO 3:L=1+(J-1)*3:A(L)=(J-1)*X(I)[(J-2):NEXT J
750 FOR J=1 TO 3:K=J-1:KK=3*K:A(KK+2)=X(I)[K:NEXT J
760 FOR J=1 TO 3:K=J-1:KK=3*K:A(KK+3)=X(I+2)[K:NEXT J
770 KS=0
780 GOSUB 5000
790 FOR J=1 TO 3:CO(I,J)=B(J):NEXT J:NEXT I
800 IF JJ=(NP-1) THEN 1140
810 OS=LOG(XN(NF))/OG-LOG(XN(NF-1))/OG
820 XI=OS/RR
830 M=(NF-2)*N+1
840 XD=LOG(XN(NF-1))/OG:XM=LOG(XN(NF))/OG
850 NL=NP-NN
860 YL=10[Y1(NL)
870 DE=CO(IN,2)+CO(IN,3)*2*XD
880 PP=CO(IN,1)
890 FOR L=2 TO 3
900 PP=PP+CO(IN,L)*XD[(L-1):NEXT L
910 DM=DE*(10[PP)*2.302585
```

```
930 GOSUB 7000
935 N3=NN+2
940 FOR I=1 TO N3
950 J=M+I:X(J)=X(M)+I*XI
960 IF X(J)<ZS THEN 1000
970 Y1(J)=LOG(YO(NF))/OG
980 GOTO 1100
1000 REM
1010 Y1(J)=B(1)
1020 FOR K=2 TO 4
1030 Y1(J)=Y1(J)+B(K)*X(J)[(K-1):NEXT K
1040 Y1(J)=LOG(Y1(J))/OG
1100 NEXT I
1110 II=NP-NN-2
1120 IN=NP-1
1130 GOTO 630
1140 IS=NP-1
1160 FOR I=1 TO LA
1180 D1=LOG(XD(I))/OG
1190 IS=NP-1
1200 FOR J=1 TO NP
1210 IF D1>X(J) THEN 1300
1220 IS=J-1
1230 J=NP
1300 NEXT J
1310 IF IS<1 THEN IS=1
1320 YD=CO(IS,1)+CO(IS,2)*D1+CO(IS,3)*D1*D1
1330 DY=10[YD
1340 LPRINT TAB(6);XD(I);TAB(20);DY;TAB(36);DY*JE/100;TAB(50);0.005*DY*JE
1350 NEXT I
1351 LPRINT TAB(6); " ":LPRINT TAB(6); "END OF TEST SERIES"
1360 LPRINT TAB(6);" ":LPRINT" ":NEXT QV
1365 PRINT TIME$
1370 PRINT "END OF RUN": END
5000 REM ROUTINE SIMQ
5010 TL=0
5020 KS=0
5030 J9=-3
5040 FOR J2=1 TO 3
5050 JY=J2+1
5060 J9=J9+3+1
5070 BA=0
5080 IT=J9-J2
5090 FOR I2=J2 TO 3
5100 IJ=IT+I2
5110 IF ABS(BA)-ABS(A(IJ))>=0 THEN 5150
5120 BA=A(IJ)
5130 IM=I2
5150 NEXT I2
5160 IF ABS(BA)-TL>0 THEN 5200
5170 KS=1
5180 J2=3:GOTO 5395
5200 I1=J2+3*(J2-2)
5210 IT=IM-J2
5220 FOR K2=J2 TO 3
5230 I1=I1+3:I3=I1+IT
5240 SA=A(I1)
5250 A(I1)=A(I3)
5260 A(I3)=SA
5270 A(I1)=A(I1)/BA:NEXT K2
5280 SA=B(IM)
5290 B(IM)=B(J2)
5300 B(J2)=SA/BA
5310 IF J2=3 THEN 5395
```

```
5340 IZ=I0+IX
5350 IT=J2-IX
5360 FOR JX=JY TO 3
5370 XX=3*(JX-1)+IX
5380 JZ=XX+IT
5390 A(XX)=A(XX)-(A(IZ)*A(JZ)):NEXT JX
5392 B(IX)=B(IX)-B(J2)*A(IZ):NEXT IX
5395 NEXT J2
5398 IF K5=1 THEN 5500
5400 NY=3-1
5410 IT=3*3
5420 FOR J2=1 TO NY
5430 IA=IT-J2
5440 IB=3-J2
5450 IC=3
5460 FOR K2=1 TO J2
5470 B(IB)=B(IB)-A(IA)*B(IC)
5480 IA=IA-3
5490 IC=IC-1:NEXT K2:NEXT J2
5500 RETURN
7000 REM ROUTINE OSCFIT
7005 PRINT "7000";TIME$;
7010 NZ=0:ST=.1:XX=XM:LX=XM-XD
7020 S1=LX/99:G8=0
7030 NZ=NZ+1
7040 L1=XD-XX:L2=-L1:L3=L1*L1:L4=L2*L2
7050 L5=L3*L1:L6=L4*L2
7060 K1=YL/L3
7070 K2=-2*YL/L5
7080 K3=YM/L4
7090 K4=-2*YM/L6
7100 K5=DM/L3
7120 B(4)=K2+K4+K5
7130 B(3)=(K1+K3-(2*XX+XD)*(K2+K5)-(2*XD+XX)*(K4))
7140 B(2)=((K2+K5)*((XX*XX)+2*XD*XX)+(K4)*((XD*XD)+2*XD*XX))
7145 B(2)=B(2)-2*K1*XX-2*K3*XD
7150 B(1)=(K1*(XX*XX)+K3*(XD*XD)-XD*(XX*XX)*(K2+K5))-(XD*XD)*XX*(K4)
7160 X2=XD-S1
7170 FOR I2=1 TO 100
7180 X2=X2+S1
7190 IF X2>XX THEN 7250
7200 YP=3*B(4)*(X2*X2)+2*B(3)*X2+B(2)
7210 W4=0:IF YP<0 THEN XX=XX-ST:I2=100:W4=1
7250 NEXT I2
7260 IF W4=1 THEN W4=0:GOTO 7030
7300 IF NZ=1 THEN 7400
7310 XX=XX+ST:ST=ST/10
7320 IF ABS(ST)<1E-6 THEN 7350
7330 GOTO 7030
7350 XX=XX-10*ST
7400 ZS=XX:PRINT TIME$:RETURN
```

```
11 REM ----------PROGRAM "JSKRAW"---------------
5 CLS
10 CLEAR 4000
15 OG=LOG(10):I2=0:XX=0:XD=0:X2=0:YP=0:ST=0:NZ=0:XM=0:LX=0:S1=0:YL=0:YM=0:IM=0:L1
=0:L2=0:L3=0:L4=0:L5=0
16 L6=0:K1=0:K2=0:K3=0:K4=0:K5=0:K6=0:JY=0:J9=0:IT=0:IJ=0:IM=0:I1=0
17 K2=0:I3=0:TL=0:KS=0:BA=0:SA=0:IQ=0:IX=0:I2=0:JX=0:IA=0:IC=0:IB=0
20 DIM XN(10),YO(10),X(53),A(16),B(4),CO(50,3),Y1(53),XD(15),XQ(10,50),YQ(10,50),
Y2(10),ID$(50),JX(50),JY(50),QQ(10,50),JQ(10),JW(10)
30 PRINT"PROGRAM SPLIN2 FROM FORTRAN ORIGINAL 02/22/82 V1"
31 LPRINT " ":LPRINT " ":LPRINT TAB(22);"SPLIN2 PROGRAM - 02/22/82 V1":LPRINT " "

40 INPUT"ENTER # OF DATA SETS";QW
45 PRINT"ENTER D50'S IN INCREASING SIZE"
46 PRINT"The last entry inputted MUST be the largest particle diameter   using th
e density entered"
50 INPUT"ENTER NUMBER OF POINTS";NF
55 FOR QV=1 TO QW
58 INPUT"SET ID=";ID$(QV):INPUT "PROCESS WGT. RATE(tons paving/hr)=";JX(QV):INPUT
 "TP EMISSION RATE (lb/hr)=";JY(QV)
59 INPUT "ENTER PARTICLE DENSITY (g/cc) ="; JQ(QV):JW(QV)=SQR(JQ(QV))
60 FOR I=1 TO NF
70 INPUT"ENTER D50, RAW LOADING FOR EACH POINT";QQ(I,QV),YQ(I,QV):XQ(I,QV)=JW(QV)
*QQ(I,QV):NEXT I
80 PRINT"SET #";QV:NEXT QV
81 INPUT"ENTER # OF D50'S TO BE DETERMINED FOR ALL SETS";LA
82 FOR I=1 TO LA:INPUT"ENTER AERODYNAMIC D50";XD(I):NEXT I
83 FOR QV=1 TO QW:FOR I=1 TO NF:XN(I)=XQ(I,QV):Y2(I)=YQ(I,QV):NEXT I
84 PRINT TIME$:LPRINT TAB(6);"TEST ID:  ";ID$(QV):LPRINT " ":LPRINT TAB(6);"INPUT
 DATA:        PROCESS WEIGHT RATE =";JX(QV);" TONS PROD. /HR":LPRINT TAB(24);"TOTA
L PARTICULATE EMISSION RATE =";JY(QV);"LB/HR":LPRINT TAB(24);"PARTICLE DENSITY ="
;JQ(QV);"G/CC "
85 LPRINT " ":LPRINT TAB(6);"MEASURED PARTICLE SIZE DISTRIBUTION":LPRINT " ":LPRI
NT TAB(6);"CUT (um)     RAW % < CUT      CUM. % < CUT":LPRINT " ":YO(0)=0:FOR I=1 T
O NF:YO(I)=YO(I-1)+Y2(I):NEXT I
86 FOR I=1 TO NF:YO(I)=YO(I)/YO(NF)*100
88 LPRINT TAB(6);QQ(I,QV) ,"     ";Y2(I),"       ";YO(I):NEXT I:LPRINT" "
89 NN=8:RR=NN:N=4:R=N
90 NP=((NF-2)*N)+NN+1
91 JE=JY(QV)/JX(QV)
92 LPRINT " ":LPRINT TAB(6);"OUTPUT DATA:     TP EMISSION FACTOR = ";JE;" LB/T  (
";0.5*JE;" KG/MT)":LPRINT " ":LPRINT " ":LPRINT TAB(39);"EMISSION FACTOR"
93 LPRINT TAB(6);"CUT (umA)     CUM. % < CUT      (LB/T)         (KG/MT)":LPRINT" "
100 N2=NF-2
110 FOR I=1 TO N2
120 JJ=N-1
130 IF N2-I<0 THEN 150
140 JJ=N+2
150 M=(I-1)*N+1
160 X(M)=LOG(XN(I))/OG
170 Y1(M)=LOG(YO(I))/OG
180 XI=(LOG(XN(I+1))/OG-LOG(XN(I))/OG)/R
190 FOR II=1 TO 3
200 MM=I-1+II
210 B(II)=LOG(YO(MM))/OG
220 K=3*(II-1)
230 FOR J=1 TO 3
240 M3=I-1+J
250 A(K+J)=(LOG(XN(M3))/OG)^(II-1)
260 NEXT J:NEXT II
270 KS=0
280 GOSUB 5000
```

```
320 B(2)=(LOG(YO(I+1)/YO(I)))/OG/(LOG(XN(I+1)/XN(I))/OG):B(1)=LOG(YO(I))/OG-B(2)*
LOG(XN(I))/OG
330 B(3)=0:J=2
350 NEXT J
360 FOR J=1 TO JJ
370 K=M+J
380 X(K)=LOG(XN(I))/OG+J*XI
390 Y1(K)=B(1)+B(2)*X(K)+B(3)*X(K)[2
400 NEXT J:NEXT I
410 FOR I=1 TO 3
420 K=3*(I-1)
430 FOR J=1 TO 3
440 M=1+(J-1)*N
450 A(K+J)=X(M)[(I-1)
460 NEXT J:NEXT I
470 FOR I=1 TO 3
480 M=1+(I-1)*N:B(I)=Y1(M):NEXT I
490 KS=0
500 GOSUB 5000
510 SL=B(2)+2*B(3)*X(1)
520 IF SL>=0 THEN 600
530 FOR I=1 TO 3:A(I)=1:NEXT I
540 A(4)=X(1)-(X(N+1)-X(1))
550 A(7)=A(4)[2
560 FOR I=1 TO 2:K=3*I:FOR J=2 TO 3
570 M=1+((J-2)*N):A(K+J)=X(M)[I:NEXT J:NEXT I
580 B(1)=Y1(1)
590 FOR I=2 TO 3:M=1+((I-2)*N):B(I)=Y1(M):NEXT I
595 KS=0:GOSUB 5000
600 FOR I=1 TO 3
610 CO(1,I)=B(I):NEXT I
615 II=1
620 IN=NP-NN-1
630 FOR I=II TO IN
640 JJ=I:B(1)=0
650 FOR J=2 TO 3
660 K=I-1
670 IF I=1 THEN K=I
680 B(1)=B(1)+(J-1)*(CO(K,J))*X(I)[(J-2)
690 NEXT J
700 B(2)=CO(K,1)
720 FOR J=2 TO 3:LET B(2)=B(2)+CO(K,J)*X(I)[(J-1):NEXT J
730 B(3)=Y1(I+2)
740 FOR J=1 TO 3:L=1+(J-1)*3:IFJ=1THENA(L)=0ELSEA(L)=(J-1)*X(I)[(J-2)
745 NEXT J
750 FOR J=1 TO 3:K=J-1:KK=3*K:A(KK+2)=X(I)[K:NEXT J
760 FOR J=1 TO 3:K=J-1:KK=3*K:A(KK+3)=X(I+2)[K:NEXT J
770 KS=0
780 GOSUB 5000
790 FOR J=1 TO 3:CO(I,J)=B(J):NEXT J:NEXT I
800 IF JJ=(NP-1) THEN 1140
810 OS=LOG(XN(NF))/OG-LOG(XN(NF-1))/OG
820 XI=OS/RR
830 M=(NF-2)*N+1
840 XD=LOG(XN(NF-1))/OG:XM=LOG(XM(NF))/OG
850 NL=NP-NN
860 YL=10[Y1(NL)
870 DE=CO(IN,2)+CO(IN,3)*2*XD
880 PP=CO(IN,1)
890 FOR L=2 TO 3
900 PP=PP+CO(IN,L)*XD[(L-1):NEXT L
910 DM=DE*(10[PP)*2.302585
920 YM=YO(NF)
930 GOSUB 7000
```

```
940 FOR I=1 TO N3
950 J=M+I:X(J)=X(M)+I*XI
960 IF X(J)<ZS THEN 1000
970 Y1(J)=LOG(YO(NF))/OG
980 GOTO 1100
1000 REM
1010 Y1(J)=B(1)
1020 FOR K=2 TO 4
1030 Y1(J)=Y1(J)+B(K)*X(J)E(K-1):NEXT K
1040 Y1(J)=LOG(Y1(J))/OG
1100 NEXT I
1110 I1=NP-NN-2
1120 IN=NP-1
1130 GOTO 630
1140 I5=NP-1
1160 FOR I=1 TO LA
1180 D1=LOG(XD(I))/OG
1190 IS=NP-1
1200 FOR J=1 TO NP
1210 IF D1>X(J) THEN 1300
1220 IS=J-1
1230 J=NP
1300 NEXT J
1310 IF IS<1 THEN IS=1
1320 YD=CO(IS,1)+CO(IS,2)*D1+CO(IS,3)*D1*D1
1330 DY=10EYD
1340 LPRINT TAB(6);XD(I);TAB(20);DY;TAB(36);DY*JE/100;TAB(50);0.005*DY*JE
1350 NEXT I
1360 LPRINT" ":LPRINT" ":NEXT QV
1362 LPRINT TAB(6);"END OF TEST SERIES"
1365 PRINT TIME$
1370 PRINT "END OF RUN": END
5000 REM ROUTINE SIMQ
5010 TL=0
5020 KS=0
5030 J9=-3
5040 FOR J2=1 TO 3
5050 JY=J2+1
5060 J9=J9+3+1
5070 BA=0
5080 IT=J9-J2
5090 FOR I2=J2 TO 3
5100 IJ=IT+I2
5110 IF ABS(BA)-ABS(A(IJ))>=0 THEN 5150
5120 BA=A(IJ)
5130 IM=I2
5150 NEXT I2
5160 IF ABS(BA)-TL>0 THEN 5200
5170 KS=1
5180 J2=3:GOTO 5395
5200 I1=J2+3*(J2-2)
5210 IT=IM-J2
5220 FOR K2=J2 TO 3
5230 I1=I1+3:I3=I1+IT
5240 SA=A(I1)
5250 A(I1)=A(I3)
5260 A(I3)=SA
5270 A(I1)=A(I1)/BA:NEXT K2
5280 SA=B(IM)
5290 B(IM)=B(J2)
5300 B(J2)=SA/BA
5310 IF J2=3 THEN 5395
5320 IQ=3*(J2-1)
5330 FOR IX=JY TO 3
```

```
5370 XX=3*(JX-1)+IX
5380 JZ=XX+IT
5390 A(XX)=A(XX)-(A(IZ)*A(JZ)):NEXT JX
5392 B(IX)=B(IX)-B(J2)*A(IZ):NEXT IX
5395 NEXT J2
5398 IF KS=1 THEN 5500
5400 NY=3-1
5410 IT=3*3
5420 FOR J2=1 TO NY
5430 IA=IT-J2
5440 IB=3-J2
5450 IC=3
5460 FOR K2=1 TO J2
5470 B(IB)=B(IB)-A(IA)*B(IC)
5480 IA=IA-3
5490 IC=IC-1:NEXT K2:NEXT J2
5500 RETURN
7000 REM ROUTINE OSCFIT
7005 PRINT "7000";TIME$;
7010 NZ=0:ST=.1:XX=XM:LX=XM-XD
7020 S1=LX/99:G8=0
7030 NZ=NZ+1
7040 L1=XD-XX:L2=-L1:L3=L1*L1:L4=L2*L2
7050 L5=L3*L1:L6=L4*L2
7060 K1=YL/L3
7070 K2=-2*YL/L5
7080 K3=YM/L4
7090 K4=-2*YM/L6
7100 K5=DM/L3
7120 B(4)=K2+K4+K5
7130 B(3)=(K1+K3-(2*XX+XD)*(K2+K5)-(2*XD+XX)*(K4))
7140 B(2)=((K2+K5)*((XX*XX)+2*XD*XX)+(K4)*((XD*XD)+2*XD*XX))
7145 B(2)=B(2)-2*K1*XX-2*K3*XD
7150 B(1)=(K1*(XX*XX)+K3*(XD*XD)-XD*(XX*XX)*(K2+K5))-(XD*XD)*XX*(K4)
7160 X2=XD-S1
7170 FOR I2=1TO 100
7180 X2=X2+S1
7190 IF X2>XX THEN 7250
7200 YP=3*B(4)*(X2*X2)+2*B(3)*X2+B(2)
7210 W4=0:IF YP<0 THEN XX=XX-ST:I2=100:W4=1
7250 NEXT I2
7260 IF W4=1 THEN W4=0:GOTO 7030
7300 IF NZ=1 THEN 7400
7310 XX=XX+ST:ST=ST/10
7320 IF ABS(ST)<1E-6 THEN 7350
7330 GOTO 7030
7350 XX=XX-10*ST
7400 ZS=XX:PRINT TIME$:RETURN
```

APPENDIX B

EXCERPTS FROM REFERENCE DOCUMENTS USED IN THE DEVELOPMENT OF PARTICULATE EMISSION FACTORS

Excerpts from

<u>REFERENCE 8 (SECTION 4.0)</u>

Rovang, R.D., Trip Report, Paul Lime Company, Douglas, Arizona, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, N.C. January 1973

Engineers Testing Laboratories, Inc.

2525 E. Indian School Rd. 264-4781 Phoenix, Arizona 85016

SEP 1972 RECEIVED ENVIRONMENTAL HEALTH

REC'D. A.D.

SEP 2_ 1972

26 SEPTEMBER 1972

PAUL LIME PLANT, INC.
P.O. DRAWER T
DOUGLAS, ARIZONA 85607

ATTENTION: HOWARD AMES, JR.
GENERAL MANAGER

RE: STACK EMISSIONS ANALYSIS ON NO. 4 KILN
RESAMPLE AFTER CHANGE OF FILTER
MEDIUM IN DUST CONTROL SYSTEM

JOB NO. 243-443
INVOICE NO. 40-807

ENCLOSED ARE THE RESULTS OF THE STACK EMISSIONS ANALYSIS PERFORMED SEPTEMBER 20, 1972 ON THE DUST COLLECTION SYSTEM FOR THE NUMBER 4 KILN OF YOUR LIME PLANT FOLLOWING THE CHANGE OF THE FILTER MEDIUM IN THE DUST CONTROL SYSTEM. THIS REPORT IS A SUPPLEMENT TO THE INITIAL STACK EMISSIONS ANALYSIS ON NO. 4 KILN REPORTED ON 29 JULY 1972 AS JOB NO. 240-386.

SUMMARY OF RESULTS

TEST NO. 4.	15 LBS. PARTICULATES PER HOUR
TEST NO. 5.	15 LBS. PARTICULATES PER HOUR

THE KILN OPERATED AT A RATE OF 15 TONS PER HOUR DURING THE TEST PERIOD. THE STATE OF ARIZONA PARTICULATE EMISSIONS STANDARD IS APPROXIMATELY 25 LBS. PER HOUR FOR THE 15 TONS PER HOUR PROCESS RATE.

RESPECTFULLY SUBMITTED,
ENGINEERS TESTING LABORATORIES, INC.

BY: R L Maurice Jr AND P Allard
R. L. MAURICE, JR. PETER F. ALLARD, P.E.
9-27-72

/FJ

COPIES TO: ADDRESSEE (3)
DIVISION OF AIR POLLUTION CONTROL (2)

DATA USED IN TEXT FOR REFERENCE 8

...MPLING LOCATION: [illegible]

...ANT CONDITION: 15 TONS PER HOUR

...ER TO BULLETIN WP-50 FOR TEST PROCEDURE, SAMPLING RATE AND FORMULAE USED.

TIME	SAMPLING POINT	GAS METER CU. FT.	GAS METER VAC. IN. Hg	GAS METER T. °F	METER RATE
0	PORT 1	196.13		74	
:30	1	200.65	5	78	
5:00	2	205.70	7.5	84	
2:30	3	210.38	8	89	
0:00	4	216.36	7.5	93	
7:30	5	221.37	7.5	97	
5:00	6	226.45	7.5	101	
2:30	7	231.44	7.5	106	
0:00	8	236.40	7.5	106	
)	PORT 2			98	
:30	1	240.80	5	103	
5:00	2	245.78	7.5	106	
2:30	3	251.15	9	111	
0:00	4	256.57	9	112	
7:30	5	261.97	9	115	
5:00	6	267.44	9	111	
2:30	7	272.90	9	110	
0:00	8	277.79	7.5	108	

FLUE OR STACK PRESSURE: INCHES OF Hg. ABS. 25.80

FLUE OR STACK TEMP. °F OR °C 360

METER VOL. (C.F.M.) 81.66

METER TEMP. (°F) 100

SAMPLE NOZZLE DIA. (INCHES) 0.188

COLLECTION, ELAPSED TIME OF TEST (MINUTES) 120

WET BULB TEMPERATURE =

DRY BULB TEMPERATURE = 360

CALCULATED MOISTURE* 5.58 % BY VOLUME

WEIGHING DATA

	CYCLONE NO.	FILTER NO. 1	IMPINGER NO. 1
GROSS		8.3563	
TARE		8.1996	
NET		0.1567	0.1263

CYCLONE NO.

FILTER NO. 0.1567

IMPINGER NO. 0.1263

TOTAL WEIGHT OF PARTICULATES .2830

DUST CONCENTRATION CALCULATIONS

TOTAL METER VOL. = 81.66 + 4.83 = 86.49 CU. FT. (METER COND.)

METER CORR. 86.49 . 1 . 820/560 = 126.65 CU. FT. (STACK COND.)

CONCENTRATION = .283 GM x 15.43 / 126.65 CU. FT. = 0.034 GR./CU. FT. (STACK COND.)

CALCULATED DUST LOAD: LBS./HR. = 0.034 GR/C.F. x 51,300 CFM x 60 / 7000 = 15

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

ETL Engineers Testing Laboratories, Inc.

SAMPLING LOCATION PAUL SPEER, ARIZONA

PLANT CONDITIONS 15 TONS PER HOUR

REFER TO BULLETIN WP-50 FOR TEST PROCEDURE, SAMPLING RATE AND FORMULAE USED.

TIME	SAMPLING POINT	GAS METER CU. FT.	GAS METER VAC. IN. Hg	GAS METER T. °F	METER RATE
0	PORT 1	277.79		96	
:45	1	280.08	7	98	
:30	2	282.56	8	101	
:15	3	284.40	8	104	
:00	4	287.65	9	105	
:45	5	290.30	10	105	
:30	6	292.15	10	105	
:15	7	294.71	10	108	
:00	8	297.89	10	111	
0	PORT 2			107	
:45	1	299.88	5	107	
:30	2	302.22	9	110	
1:15	3	304.05	10	111	
5:00	4	307.32	12	114	
8:45	5	309.95	12	116	
2:30	6	311.97	13	117	
6:15	7	315.35	14	120	
0:00	8	317.86	15	120	

FLUE OR STACK PRESSURE: INCHES OF Hg. ABS. 25.64

FLUE OR STACK TEMP. °F OR °C 360

METER VOL. (C.F.M.) 40.07

METER TEMP. (°F) 109

SAMPLE NOZZLE DIA. (INCHES) 0.188

COLLECTION, ELAPSED TIME OF TEST (MINUTES) 60

WET BULB TEMPERATURE =

DRY BULB TEMPERATURE = 360

CALCULATED MOISTURE 7.29 % BY VOLUME

WEIGHING DATA

	CYCLONE NO.	FILTER NO. 2	IMPINGER NO. 2
GROSS		8.0206	
TARE		7.9408	
NET		0.0798	0.0628

CYCLONE NO.		
FILTER NO.	2	0.0798
IMPINGER NO.	2	0.0628
TOTAL WEIGHT OF PARTICULATES		.1426

DUST CONCENTRATION CALCULATIONS

TOTAL METER VOL. = 40.07 + 3.15 = 43.22 CU. FT. (METER COND.)

METER CORR. = 43.22 × 1 × $\frac{820}{569}$ = 62.28 CU. FT. (STACK COND.)

CONCENTRATION = $\frac{.1426 \text{ GM} \times 15.43}{62.28 \text{ CU. FT.}}$ = 0.035 GR./CU. FT. (STACK COND.)

CALCULATED DUST LOAD LBS./HR. = 0.035 GR/C.F. × $\frac{51,500 \text{ CFM} \times 60}{7000}$ = $\boxed{15}$

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

REFERENCE 10 (SECTION 4.0)

Maurice, R. L., and P. F. Allard, Stack Emissions on No. 5 Kiln, Paul Lime Plant, Inc., Engineers Testing Laboratories, Inc., Phoeniz, AZ, June 1973.

Engineers Testing Laboratories, Inc.

2525 E. Indian School Rd. 264-4731 Phoenix, Arizona 85016

26 June 1973

PAUL LIME PLANT, INC.
P. O. DRAWER T
DOUGLAS, ARIZONA 85607

ATTENTION: HOWARD AMES, JR., GENERAL MANAGER

JOB NO. 343-279
INVOICE NO. 40-1130

RE: STACK EMISSIONS ON NO. 5 KILN

ENCLOSED ARE THE RESULTS OF THE STACK EMISSIONS ANALYSIS PERFORMED JUNE 6 AND 7, 1973 ON THE DUST COLLECTION SYSTEM FOR THE NUMBER 5 KILN OF YOUR LIME PLANT.

SUMMARY OF RESULTS

TEST NO. 1	13.8 LBS. PARTICULATE/HOUR
TEST NO. 2	9.9 LBS. PARTICULATE/HOUR
TEST NO. 3	10.9 LBS. PARTICULATE/HOUR

340 TPD LIME PRODUCED, GAS FIRED

THE KILN OPERATED AT A RATE OF 25.2 TONS PER HOUR DURING THE TEST PERIOD. THE STATE OF ARIZONA PARTICULATE EMISSIONS STANDARD IS APPROXIMATELY 36 LBS. PER HOUR FOR THE 25.2 TONS PER HOUR PROCESS RATE.

RESPECTFULLY SUBMITTED,
ENGINEERS TESTING LABORATORIES, INC.

BY: R. L. Maurice, Jr. AND P. Allard
R. L. MAURICE, JR. by Ra PETER F. ALLARD, P. E.

/JH

COPIES TO: ADDRESSEE (2)
DIVISION OF AIR POLLUTION CONTROL (2)

DATA USED IN TEXT FOR REFERENCE 10

PLANT CONDITION: ____________________

REFER TO BULLETIN WP-50 FOR TEST PROCEDURE, SAMPLING RATE AND FORMULAE USED

TIME	SAMPLING POINT	GAS METER CU. FT.	GAS METER VAC. IN. Hg	GAS METER T. °F	METER RATE
PORT #1 0.0MIN	1	0.06	3	92	
7.5	2	3.10	4	96	
15	3	6.56	5	99	
22.5	4	10.38	5	102	
PORT #2 30	1	14.37	2	107	
37.5	2	17.28	3	110	
45	3	20.27	4	111	
52.5	4	23.64	6	112	
PORT #3 60	1	27.53	2	113	
67.5	2	30.29	3	114	
75	3	33.19	5	115	
82.5	4	36.61	7	117	
PORT #4 90	1	40.46	4	118	
97.5	2	43.18	4	117	
105	3	46.07	6	120	
112.5	4	49.33	7	121	
120		52.92		120	
		52.86		111	

FLUE OR STACK PRESSURE: INCHES OF Hg. ABS. 26.10

METER TEMP. °F 111

METER VOLUME (C.F.) 52.86

FLUE OR STACK TEMPERATURE (°F) 400

SAMPLE NOZZLE DIA. (INCHES) 1/8

COLLECTION, ELAPSED TIME OF TEST (MINUTES) 120

WET BULB TEMPERATURE = N/A

DRY BULB TEMPERATURE = N/A

WATER VAPOR BY CONDENSATION 7.0 % BY VOLUME

WEIGHING DATA

	PROBE	FILTER NO.	IMPINGER NO.
GROSS	27.2919	8.0634	27.1903
TARE	27.2700	8.0162	27.1832
NET	0.0219	0.0472	0.0071

PROBE	0.0219
FILTER NO.	0.0472
IMPINGER NO.	0.0071
TOTAL WEIGHT OF PARTICULATES	0.0762

DUST CONCENTRATION CALCULATIONS

TOTAL METER VOL. = 52.86 + 3.98 = 56.84 CU. FT. (METER COND.)

METER CORR. = $56.84 \times \frac{860}{571} \times \_\_\_ = 85.61$ CU. FT. (STACK COND.)

CONCENTRATION $\frac{0.0762 \text{ GM} \times 15.43}{85.61 \text{ CU. FT.}} = 0.014$ GR./CU. FT. (STACK COND.)

CALCULATED DUST LOAD, LBS./HR. = $\frac{0.014 \text{ GR/C.F.} \times 115,000 \text{ CFM} \times 60}{7000} = \boxed{13.8}$

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

ETL Engineers Testing Laboratories, Inc.

FOR: PAUL LIME PLANT, INC. DATE: 6-6-73 TEST NO. 2

SAMPLING LOCATION: #5 KILN

PLANT CONDITIONS:

REFER TO BULLETIN WP-50 FOR TEST PROCEDURE, SAMPLING RATE AND FORMULAS USED

TIME	SAMPLING POINT	GAS METER			METER RATE
		CU. FT.	VAC. IN. Hg	T. °F	
PORT #1 0.0MIN.	1	52.92	2	104	
7.5	2	56.05	2	107	
15	3	59.46	3	109	
22.5	4	63.26	4	109	
PORT #2 30	1	67.29	2	111	
37.5	2	70.28	3	115	
45	3	73.29	3	118	
52.5	4	76.70	4	119	
PORT #3 60	1	80.59	2	116	
67.5	2	83.43	3	117	
75	3	86.34	4	116	
82.5	4	89.79	6	115	
PORT #4 90	1	93.69	2	114	
97.5	2	96.44	3	116	
105	3	99.25	4	115	
112.5	4	102.55	4	117	
120		106.10		118	
		53.18		114	

FLUE OR STACK PRESSURE INCHES OF Hg. ABS. 26.00

METER TEMP. °F 114

METER VOLUME (C.F.) 53.18

FLUE OR STACK TEMPERATURE (°F) 405

SAMPLE NOZZLE DIA. (INCHES) 1/8

COLLECTION, ELAPSED TIME OF TEST (MINUTES) 120

WET BULB TEMPERATURE = N/A

DRY BULB TEMPERATURE = N/A

WATER VAPOR BY CONDENSATION 6.8 % BY VOLUME

WEIGHING DATA

	PROBE	FILTER NO.	IMPINGER NO.
GROSS	27.2502	8.6087	26.7669
TARE	27.2418	8.5625	26.7651
NET	0.0084	0.0462	0.0018

PROBE	0.0084
FILTER NO.	0.0462
IMPINGER NO.	0.0018
TOTAL WEIGHT OF PARTICULATES	0.0564

DUST CONCENTRATION CALCULATIONS

TOTAL METER VOL. = 53.18 + 3.88 = 57.06 CU. FT. (METER COND.)

METER CORR. = $57.06 \times \frac{865}{574}$ = ____ = 85.99 CU. FT. (STACK COND.)

CONCENTRATION $\frac{0.0564 \text{ GM} \times 15.43}{85.99 \text{ CU. FT.}}$ = 0.010 GR./CU. FT. (STACK COND.)

CALCULATED DUST LOAD LBS./HR. = $\frac{0.010 \text{ GR/C.F.} \times 115{,}000 \text{ CFM} \times 60}{7000}$ = $\boxed{9.9}$

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

ETL Engineers Testing Laboratories, Inc.

JOB PAUL LIME PLANT, INC. DATE 6-7-73 TEST NO. 3

SAMPLING LOCATION #5 KILN

PLANT CONDITIONS

REFER TO BULLETIN WP-50 FOR TEST PROCEDURE, SAMPLING RATE AND FORMULAE USED

TIME	SAMPLING POINT	GAS METER CU. FT.	GAS METER VAC. IN. Hg	GAS METER T. °F	METER RATE
PORT #1 0.0 MIN.	1	6.10	2	96	
7.5	2	9.19	3	96	
15.0	3	12.61	4	95	
22.5	4	16.54	3	98	
PORT #2 30	1	20.29	2	98	
37.5	2	23.25	2	100	
45	3	26.24	3	101	
52.5	4	29.67	5	102	
PORT #3 60	1	33.63	2	102	
67.5	2	36.42	3	103	
75	3	39.35	4	104	
82.5	4	42.79	5	105	
PORT #4 90	1	46.66	2	104	
97.5	2	49.27	3	106	
105	3	52.14	4	108	
112.5	4	55.46	5	110	
120		59.30		113	
		53.20		102	

FLUE OR STACK PRESSURE: INCHES OF Hg. A. 26.02

METER TEMP. °F 102

METER VOLUME (C.F.) 53.20

FLUE OR STACK TEMPERATURE (°F) 400

SAMPLE NOZZLE DIA. (INCHES) 1/8

COLLECTION, ELAPSED TIME OF TEST (MINUTES) 120

WET BULB TEMPERATURE = N/A

DRY BULB TEMPERATURE = N/A

WATER VAPOR BY CONDENSATION 6.6 % BY VOLUME

WEIGHING DATA

	PROBE	FILTER NO.	IMPINGER NO.
GROSS	27.5913	8.1080	27.4401
TARE	27.5741	8.0658	27.4396
NET	0.0172	0.0422	0.0005

PROBE	0.0172
FILTER NO.	0.0422
IMPINGER NO.	0.0005
TOTAL WEIGHT OF PARTICULATES	0.0599

DUST CONCENTRATION CALCULATIONS

TOTAL METER VOL. = 53.20 + 3.76 = 56.96 CU. FT. (METER COND.)

METER CORR. = 56.95 × 860/562 = 87.16 CU. FT. (STACK COND.)

CONCENTRATION = 0.0599 GM × 15.43 / 87.16 CU. FT. = 0.011 GR./CU. FT. (STACK COND.)

CALCULATED DUST LOAD LBS./HR. = 0.011 GR/C.F. × 116,000 FT³/MIN × 60 / 7000 = $\boxed{10.9}$

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Engineers Testing Laboratories, Inc.

Excerpts from

REFERENCE 12 (SECTION 4.0)

Air Pollution Emission Test, Dow Chemical,
Freeport, TX, Project Report No. 74-LIM-6,
U. S. Environmental Protection Agency,
Office of Air Quality Planning and Standards,
Research Triangle Park, N.C., May 1974.

Table 2.1 Particulate Data Summary (English)

RUN NUMBER	1		2		3			
DATE	April 30, 1974		May 2, 1974		May 3, 1974		Averages	
STACK DESIGNATION	NORTH	SOUTH	NORTH	SOUTH	NORTH	SOUTH	NORTH	SOUTH
Volume of Gas Sampled, DSCF (1)	43.39	99.62	131.33	131.66	133.72	136.15	102.81	122.48
Percent Moisture By Volume	18.5	17.1	17.6	17.9	18.2	18.6	18.1	17.9
Average Stack Temperature, °F	373	449	361	412	366	406	367	422
Stack Volumetric Flow Rate, DSCFM	49,144	47,834	45,911	42,945	46,318	45,693	47,124	45,490
Stack Volumetric Flow Rate, ACFM	93,559	97,870	85,521	85,190	87,951	91,500	89,010	91,520
Percent Isokinetic	128	119	103	110	104	110	111	113
Process Weight Rate, Ton/Hr (2)	20.3	20.3	20.0	20.0	20.3	20.3	20.2	20.2
PARTICULATES - PROBE AND FILTER								
Mg	46.7	39.5	30.6	21.9	51.2	49.5	42.8	37.0
Gr/DSCF (3)	0.0166	0.0061	0.0036	0.0025	0.0059	0.0056	0.0087	0.0047
Gr/ACF	0.0087	0.0029	0.0019	0.0013	0.0031	0.0028	0.0046	0.0023
Lb/Hr	7.00	2.51	1.42	0.95	2.35	2.20	3.59	1.89
Lb/Ton Feed	0.344	0.124	0.071	0.048	0.116	0.108	0.177	0.093
PARTICULATES, TOTAL								
Mg	84.2	63.9	49.4	126.4	71.2	105.7	68.3	99.0
Gr/DSCF	0.0299	0.0099	0.0058	0.0147	0.0082	0.012	0.0146	0.0122
Gr/ACF	0.0157	0.0047	0.0031	0.0074	0.0043	0.006	0.0077	0.0060
Lb/Hr	12.62	4.06	2.28	5.45	3.26	4.74	6.05	4.75
Lb/Ton Feed	0.62	0.20	0.114	0.272	0.161	0.233	0.298	0.235
Percent Impinger Catch	44.5	38.2	38.1	82.7	28.1	53.6	36.9	58.2

(1) Dry standard cubic feet at 70°F and 29.92 inches Hg.
(2) These values are averages for the kilns (see Table 3.1) i.e. total feed rate for run #1 was 40.6 ton per hour.
(3) Grains per DSCF.

DATA USED IN TABLE 4-1 AND CALCULATIONS IN APPENDIX C

Excerpts from

REFERENCE 13 (SECTION 4.0)

Schock, J. B., Exhaust Gas Emission Study,
J. E. Baker Company, Millersville, OH,
George D. Clayton and Associates, Southfield, MI,
June 1974.

EXHAUST GAS EMISSION STUDY

J.E. BAKER COMPANY
Millersville, Ohio

INTRODUCTION

The J.E. Baker Company retained George D. Clayton & Associates to evaluate the emissions from the Fuller cooler stack on the No. 2 kiln and the scrubber exhaust stack on the No. 1 kiln at its operations in Millersville, Ohio. The study included the measurement of particulate emission rates, exhaust gas composition, temperature and flowrates. Additionally, sulfur oxides emission rates were measured on the scrubber outlet.

Messrs. Robert J. Brumer and Jonathan B. Schoch of Clayton & Associates conducted the study on May 21-23, 1974. Messrs. Peter Hess of the Ohio EPA, Anthony Maccari of Air Pollution Industries, Inc. and Lewis H. Dorward of the J.E. Baker Company also observed the testing.

DESCRIPTION OF PROCESS

Dolomite stone from the adjacent quarry is screened, washed, dried and conveyed to hoppers where it is stored prior to feeding to either of the two rotary kilns. Stone and coal are fed to the No. 1 kiln to form dolomitic lime, while stone, coal, and flux are fed to the No. 2 kiln to form dead-burned dolomite. As the stone slowly tumbles down the kiln, hot exhaust gases from the combustion of the coal travel counter-currently to it. The calcium and magnesium carbonates decompose in the kiln to form calcium and magnesium oxides and carbon dioxide. Entrained dust, combustion gases and by-product carbon dioxide from the No. 1 kiln are discharged to the wet scrubber.

The scrubber is a venturi type manufactured by Air Pollution Industries, Inc. which sprays approximately 2,200 gallons of water per minute and operates at a pressure drop of approximately 13.5 inches of water across the venturi throat. The cleaned gas is then exhausted to the stack, while the dirty scrubber water is sent to a settling pond located in the quarry. This water is then recycled.

At the lower end of the No. 2 rotary kiln, the hot dead-burned dolomite leaves the kiln and falls onto a grid. A centrifugal fan forces air up through the grid cooling the dolomite to temperatures at which it can be conveyed. After passing through the grid, the cooling air either enters the kiln, where it is used as combustion air, or is exhausted through the cooler stack.

Plant J.E. Baker Company, Millersville, Ohio Stack Fuller Cooler Stack - Kiln No. 2

Material Sampled	Test Number	1974 Date	Sampling Period	Stack Temp °F	Stack Flowrate SCFM Dry	Concentration gr/SCFD	Emission Rate lbs/hr	Opacity %	Process Weight Rate tons/hr
Filterable Particulate	1	5/21	13:00-14:00	116	14,800	0.086	10.9	0	9.8
Filterable Particulate	2	5/21	15:20-16:20	115	14,800	0.076	9.7	0	9.8
Filterable Particulate	3	5/21	16:42-17:42	115	14,800	0.127	16.1	0	9.8
1) Average				115	14,800	0.096	12.2	0	9.8
Total Particulate	1	5/21	13:00-14:00	116	14,800	0.088	11.1	0	9.8
Total Particulate	2	5/21	15:20-16:20	115	14,800	0.080	10.1	0	9.8
Total Particulate	3	5/21	16:42-17:42	115	14,800	0.130	16.5	0	9.8
Average				115	14,800	0.099	12.6	0	9.8

DATA USED IN TEXT FOR REFERENCE 13 AND IN CALCULATIONS SHOWN IN APPENDIX C

Plant J.E. Baker Company, Millersville, Ohio   Stack Scrubber Exhaust Stack - Kiln No. 1

Material Sampled	Test Number	1974 Date	Sampling Period	Stack Temp °F	Stack Flowrate SCFM Dry	Concentration gr/SCFD	Emission Rate lbs/hr	Opacity %	Process Weight Rate tons/hr
Filterable Particulate	1	5/22	13:16-15:31	151	58,700	0.101	51.0	10-15	35.39
Filterable Particulate	2	5/23	09:17-11:32	150	53,000	0.102	46.3	10-15	35.15
Filterable Particulate	3	5/23	12:16-14:31	150	56,300	0.127	61.5	10-15	35.15
Average				150	56,000	0.110	52.9	10-15	35.23
Total Particulate	1	5/22	13:16-15:31	151	58,700	0.118	59.3	10-15	35.39
Total Particulate	2	5/23	09:17-11:32	150	53,000	0.129	58.7	10-15	35.15
Total Particulate	3	5/23	12:16-14:31	150	56,300	0.138	66.7	10-15	35.15
Average				150	56,000	0.128	61.6	10-15	35.23

DATA USED IN TEXT FOR REFERENCE 13 AND IN CALCULATIONS SHOWN IN APPENDIX C

~17.6 T/hr

SUMMARY OF PROCESS DATA

J.E. BAKER COMPANY
Millersville, Ohio

May 21-23, 1974

eration and roduct	1974 Date	Source and Test Number	Time Period	Averages					
				Kiln Speed turns/hr	Coal Feedrate tons/hr	Stone Feedrate tons/hr	Flux Feedrate tons/hr	Product Rate tons/hr	Natural Gas Feedrate ft^3/hr
n No. 2 d-burned omite	5/21	Cooler Stack P-1,2,3	12:00-19:00	38.75	3.125	17.9	0.645	9.8	Not Used
n No. 2 d-burned omite	5/21	Cooler Stack P-1,2,3	24 Hours	38.7	3.10	19.44	0.68	9.72	Not Used
n No. 1 omitic e	5/22	Scrubber Stack P-1 SO_x-1,2,3	12:00-20:00	71.1	4.49	30.9	Not Used	13.3	Not Availabl
n No. 1 omitic e	5/22	Scrubber Stack P-1 SO_x-1,2,3	24 Hours	72	4.42	30.0	Not Used	12.93	6995
n No. 1 omitic e	5/23	Scrubber Stack P-2,3	08:00-15:00	73.1	4.25	30.9	Not Used	13.29	Not Availabl
n No. 1 omitic e	5/23	Scrubber Stack P-2,3	24 Hours	Not Available	4.30	30.62	Not Used	13.17	7050

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

REFERENCE 14 (SECTION 4.0)

Eggleston, T. E., Air Pollution Emission Test,
Bethlehem Mines Corporation, Annville, PA,
EMB Test No. 74-LIM-1, U.S. Environmental
Protection Agency, Office of Air Quality Planning
and Standards, Research Triangle Park, NC,
August 1974.

TABLE 1

SUMMARY OF PARTICULATE RESULTS

DATE		1-22-74	1-23-74	1-24-74	AVERAGE
RUN		LM-1	LM-2	LM-3	
"A" DUCT:	TOTAL TRAIN				
	gr/scf*	0.024	0.024	0.025	0.024
	lb/hr	2.77	2.25	3.39	2.80
	FRONT HALF**				
	gr/scf*	0.020	0.021	0.021	0.021
	lb/hr	2.32	1.98	2.78	2.36
	% of total	83.8	88.0	82.0	84.3
"B" DUCT:	TOTAL TRAIN				
	gr/scf*	0.035	0.041	0.051	0.042
	lb/hr	5.13	7.83	7.01	6.66
	FRONT HALF**				
	gr/scf*	0.032	0.036	0.048	0.039
	lb/hr	4.62	6.92	6.62	6.05
	% of total	90.1	88.4	94.4	90.8
SYSTEM:	TOTAL TRAIN				
	gr/scf*	0.0305	0.0354	0.0380	0.0346
	lb/hr	15.80	20.16	20.80	18.92
	FRONT HALF**				
	gr/scf*	0.0268	0.0310	0.0340	0.0306
	lb/hr	13.88	17.80	18.80	16.83
	% of total	87.8	88.3	90.4	89.0
TOTAL:	lb/ton of feed	0.263	0.336	0.347	0.315

CORRECTED FOR IMPINGER CATCH

* $70^{o}F$, 29.92" Hg, dry

** Probe & Filter

DATA USED IN TABLE 4-1 AND IN CALCULATIONS SHOWN IN APPENDIX C

TABLE 5

Summary of Operating Variables

Date	1/22	1/23	1/24
Test No.	1	2	3
Stone feed rate (tons/hr)	60	60	60
Coal feed rate (tons/hr)	5.1-5.5	5.25	5.5
Water (gallons/min)	28-29	28	31
Pressure drop (inches of W.C.)	4.3-4.4	4.3-4.4	4.1-4.3
Kiln speed (RPH)	78	78	78
Feed end temp. (°F)	915-925	910-920	920-930
Product temp. (°F)	175-185	160-180	160-165
Baghouse inlet temp. (°F)	505-520	485-490	520-530

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

<u>REFERENCE 17 (SECTION 4.0)</u>

Air Pollution Emission Test, Marblehead Lime Company, Gary, Indiana, Report No. 74-LIM-7, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 1974.

TABLE 2-1

PARTICULATE SUMMARY
ENGLISH UNITS

Run Number / Date	1 (June 11, 1974)	2 (June 11, 1974)	3 (June 12, 1974)	4 (June 12, 1974)	5 (June 13, 1974)	6 (June 13, 1974)	Average
Volume of Gas Sampled-DSCF	181.62	162.69	163.91	167.19	192.74	182.32	175.08
Percent Moisture by Volume	6.5	4.8	6.3	7.5	7.4	6.5	6.5
Average Stack Temperature-°F	291	263	284	269	272	273	275
Stack Volumetric Flow Rate-DSCFM	23,797	22,407	23,162	21,247	24,878	23,156	23,108
Stack Volumetric Flow Rate-ACFM	37,049	33,031	35,532	32,375	38,024	35,078	35,182
Percent Isokinetic	98.5	93.7	91.4	101.6	100.0	101.6	97.8
Percent Stack Opacity	0.031	0.005	0.055	0.000	0.031	0.003	0.021
Feed Rate-ton/hr. (limestone only)	37.76	37.76	38.63	38.63	38.21	38.21	38.20
Particulates - Probe & Filter Catch							
mg.	262.4	223.1	104.6	118.1	156.2	137.0	166.9
gr/DSCF	0.0223	0.0216	0.0098	0.0109	0.0125	0.0116	0.0148
gr/ACF	0.0143	0.0146	0.0064	0.0072	0.0082	0.0077	0.0097
lb/hr	4.55	4.15	1.96	1.98	2.67	2.30	2.92
lb/ton feed	0.1205	0.1099	0.0507	0.0513	0.0700	0.0602	0.0771
TOTAL FOR SIX STACKS 0.463 lbs/ton FEED							
Particulates - Total Catch							
[illegible]	424.5	426.0	340.0	275.0	320.4	377.0	360.5
gr/DSCF	0.0361	0.0404	0.0320	0.0254	0.0257	0.0319	0.0319
gr/ACF	0.0232	0.0274	0.0209	0.0167	0.0168	0.0210	0.0210
lb/hr	7.36	7.76	6.36	4.62	5.47	6.33	6.32
lb/ton feed	0.1949	0.2055	0.1646	0.1196	0.1432	0.1657	0.1656
Percent Impinger Catch	38.2	47.6	69.2	57.1	51.2	63.7	54.5

2-2

DATA USED IN TABLE 4-1

TABLE 2-2

PARTICULATE SUMMARY
METRIC UNITS

Run Number / Date	1 (June 11, 1974)	2 (June 11, 1974)	3 (June 12, 1974)	4 (June 12, 1974)	5 (June 13, 1974)	6 (June 13, 1974)	Average
Volume of Gas Sampled-Nm^3	5.14	4.61	4.64	4.73	5.46	5.16	4.96
Percent Moisture by Volume	6.5	4.8	6.3	7.5	7.4	6.5	6.5
Average Stack Temperature-°C	143.9	128.3	140.0	131.7	133.3	133.9	135.2
Stack Volumetric Flow Rate-Nm^3/min	674	635	656	602	705	656	655
Stack Volumetric Flow Rate-m^3/min	1,049	935	1,006	917	1,077	993	996
Percent Isokinetic	98.5	93.7	91.4	101.6	100.0	101.6	97.8
Percent Stack Opacity	0.031	0.005	0.055	0.000	0.031	0.003	0.021
Feed Rate-M ton/hr (limestone only)	34.26	34.26	35.04	35.04	34.66	34.66	34.65
Particulates - Probe & Filter Catch							
mg.	262.4	223.1	104.6	118.1	156.2	137.0	166.9
mg/Nm^3	51.1	48.4	22.5	25.0	28.6	26.6	33.7
mg/m^3	32.8	32.8	14.7	16.4	18.7	17.6	22.2
kg/hr	2.07	1.84	0.89	0.90	1.21	1.05	1.33
kg/M ton	0.0604	0.0537	0.0254	0.0257	0.0349	0.0303	0.0384
Particulates - Total Catch							
mg.	424.5	426.0	340.0	275.0	320.4	377.0	360.5
mg/Nm^3	82.6	92.4	73.3	58.1	58.7	73.1	73.0
mg/m^3	53.1	62.7	47.7	30.1	38.4	48.2	48.1
kg/hr	3.34	3.52	2.88	2.10	2.48	2.87	2.87
kg/M ton	0.0975	0.1027	0.0822	0.0599	0.0715	0.0828	0.0828
Percent Impinger Catch	38.2	47.6	69.2	57.1	51.2	63.7	54.5

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

REFERENCE 20 (SECTION 4.0)

Air Pollution Emission Test, U. S. Lime Division, Flintkote Company, City of Industry, CA, Report No. 74-LIM-5, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, October 1974.

SET 2510 02 0S74

Table 1 SUMMARY OF RESULTS
(British Units)

Run Number	1	2	3	Average
Date:	4/16/74	4/17/74	4/18/74	
Volume of Gas Sampled - DSCF (a)	74.2	80.6	80.5	78.4
Percent Moisture by Volume **	44.5	48.0	47.5	46.7
Average Stack Temperature - °F	174	178	177	176
Stack Volumetric Flow Rate -DSCFM (b)	4901	4775	4797	4824
Stack Volumetric Flow Rate -ACFM (c)	10701	11154	11084	10980
Percent Isokinetic	101.3	115.7	106.7	107.9
Percent Opacity	0	0	0	0
Feed Rate - ton/hr	14	14	14	14
Particulate - probe, cyclone, & filter catch				
mg	104.2	140.8	191.3	145.4
gr/DSCF	0.02164	0.02690	0.03658	0.02855*
gr/ACF	0.00991	0.01151	0.01583	0.01248*
lb/hr	0.91	1.10	1.50	1.17
lb/ton feed	0.065	0.079	0.107	0.084
Particulate - total catch				
mg	129.6	181.3	211.0	174.0
gr/DSCF	0.02691	0.03463	0.04034	0.03415*
gr/ACF	0.01233	0.01483	0.01746	0.01494*
lb/hr	1.13	1.42	1.66	1.40
lb/ton feed	0.081	0.101	0.119	0.100
Percent Impinger Catch	19.6	22.3	9.34	17.1

DATA USED IN TABLE 4-1

(a) Dry standard cubic feet at 70°F, 29.92 in.Hg.
(b) Dry standard cubic feet per minute at 70°F, 29.92 in.Hg.
(c) Actual cubic feet per minute.
* Weighted Averages
** Based on saturated psychrometric values at stack temperature.

SET 2510 02 0874

Table 2 SUMMARY OF RESULTS
(Metric Units)

Run Number	1	2	3	Average
Date:	4/16/74	4/17/74	4/18/74	
Volume of Gas Sampled - Nm^3 (a)	2.100	2.281	2.278	2.220
Percent Moisture by Volume **	44.5	48.0	47.5	46.7
Average Stack Temperature - °C	78.9	81.1	80.6	80.2
Stack Volumetric Flow Rate-Nm^3/min (b)	138.8	135.2	135.8	136.6
Stack Volumetric Flow Rate-m^3/min (c)	303.0	315.8	313.9	310.9
Percent Isokinetic	101.3	115.7	106.7	107.9
Percent Opacity	0	0	0	0
Feed Rate - M.ton/hr	12.7	12.7	12.7	12.7
Particulate - probe, cyclone, and filter catch				
mg	104.2	140.8	191.3	145.4
mg/Nm^3	49.6	61.7	84.0	65.5*
mg/m^3	22.7	26.3	36.2	28.6*
kg/hr	0.40	0.48	0.66	0.51
kg/M ton	0.031	0.038	0.052	0.040
Particulates - total catch				
mg	129.6	181.3	211.0	174.0
mg/Nm^3	61.7	79.5	92.6	78.4
mg/m^3	28.2	33.9	39.9	34.2
kg/hr	0.49	0.61	0.73	0.61
kg/M ton	0.039	0.048	0.057	0.048
Percent Impinger Catch	19.6	22.3	9.34	17.1

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

(a) Dry normal cubic meter at 21.1°C and 760 mm Hg.
(b) Dry normal cubic meters per minute at 21.1°C, 760 mm Hg.
(c) Actual cubic meters per minute.
* Weighted average.
** Based on saturated psychrometric values at stack temperature.

SET 2510 02 0S74

Three baghouse collectors controlled emissions from loading, milling, sacking, screening and separating processes in the lime plant. No visible emissions were apparent from these collectors. No sampling of these emissions was done.

According to Flintkote and EPA process data, the plant was operating normally throughout all three tests. The process shut down for approximately five minutes during the second test due to a blocked feed screw and may result in a slightly lower particulate catch for that test. All three tests appeared to be successful.

TABLE 3 - SUMMARY OF ATMOSPHERIC HYDRATOR AND WATER SCRUBBER OPERATING DATA DURING SAMPLING

Date	4/16/74	4/17/74	4/18/74
Test No.	1	2	3
Lime Feed Rate (tons/hr)	14	14	14
Water Feed Rate (tons/hr)	7	7	7
Hydrated Lime Production (tons/hr)	17-18	17-18	17-18
Scrubber Water (lbs/min)	160-166	165-168	165-169
Scrubber Temp. before airbleed (°F)	203-206	202-210	208-215
Scrubber Temp. after airbleed (°F)	184-192	188-192	188-192

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

REFERENCE 21 (SECTION 4.0)

Air Pollution Emission Test, J. M. Brenner Company, Lancaster, PA, EPA Project No. 75-STN-7, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, November 1974.

TABLE I

SUMMARY OF PARTICULATE* EMISSIONS

J.M. Brenner Company
Lancaster, Pennsylvania
November 19-22, 1974

Sampled Source: Outlet A Dimensions: 16" x 13-1/4"

Test Number		1	2	3
Date		11-19	11-21	11-22
Sampling Period	Start	14:21	12:10	09:03
	Stop	16:23	16:20	13:59
Sampled Volume	Am^3 (1)	1.547	7.088	7.173
	DNm^3 (2)	1.524	7.219	7.403
	ACF (3)	54.64	250.3	253.3
	DSCF (4)	53.80	254.9	261.4
Percent Moisture by Volume		1.0	0.4	0.1
Average Stack Temperature	°C	19	3.3	6.7
	°F	66	38	44
Stack Gas Flowrate	Am^3/sec (5)	3.46	3.57	3.55
	DNm^3/sec (6)	3.43	3.64	3.68
	ACFM (7)	7340	7560	7520
	DSCFM (8)	7260	7720	7800
Percent Isokinetic		106.6	97.3	98.9
Feed Rate	M tons/hr (9)	120	108	115
	tons/hr	132	119	127
Sample Weight (mg)		10.3	11.9	44.1
Particulate Concentration	mg/Am^3	6.7	1.7	6.1
	mg/DNm^3	6.8	1.6	6.0
	gr/ACF	0.003	0.0007	0.003
	gr/DSCF	0.003	0.0007	0.003
Particulate Emission Rate	kg/hr	0.08	0.02	0.08
	kg/M ton of feed	0.0007	0.0002	0.0007
	lb/hr	0.18	0.05	0.17
	lb/ton of feed	0.001	0.0004	0.001

DATA USED IN TABLE 4-1 AND IN CALCULATIONS SHOWN IN APPENDIX C

(1) Actual cubic meters - stack conditions
(2) Dry normal cubic meters - 20°C, 760 mm Hg
(3) Actual cubic feet - stack conditions
(4) Dry standard cubic feet - 20°C, 760 mm Hg
(5) Actual cubic meters per second - stack conditions
(6) Dry normal cubic meters per second - 20°C, 760 mm Hg
(7) Actual cubic feet per minute - stack conditions
(8) Dry standard cubic feet per minute - 20°C, 760 mm Hg
(9) Metric tons per hour (1 metric ton = 1000 kg)

* EPA Method 5

TABLE I

SUMMARY OF PARTICULATE* EMISSIONS

J.M. Brenner Company
Lancaster, Pennsylvania
November 19-22, 1974

Sampled Source: Outlet B   Dimensions: 16" x 13-1/2"

Test Number		1	2	3
Date		11-19	11-21	11-22
Sampling Period	Start	14:22	12:05	08:58
	Stop	16:24	16:15	13:54
Sampled Volume	Am^3 (1)	2.951	6.777	6.355
	DNm^3 (2)	2.948	6.763	6.488
	ACF (3)	104.2	239.3	224.4
	DSCF (4)	104.1	238.8	229.1
Percent Moisture by Volume		0.4	0.3	0.1
Average Stack Temperature	°C	17	10	11
	°F	62	50	51
Stack Gas Flowrate	Am^3/sec (5)	2.94	3.24	3.09
	DNm^3/sec (6)	2.95	3.25	3.16
	ACFM (7)	6220	6870	6540
	DSCFM (8)	6260	6880	6700
Percent Isokinetic		102.0	106.4	104.8
Feed Rate	M tons/hr (9)	120	108	115
	tons/hr	132	119	127
Sample Weight (mg)		38.7	0.5	5.5
Particulate Concentration	mg/Am^3	13.1	0.07	0.87
	mg/DNm^3	13.1	0.07	0.85
	gr/ACF	0.006	0.00003	0.0004
	gr/DSCF	0.006	0.00003	0.0004
Particulate Emission Rate	kg/hr	0.14	0.0009	0.01
	kg/M ton of feed	0.001	0.000008	0.00008
	lb/hr	0.31	0.002	0.02
	lb/ton of feed	0.002	0.00002	0.0002

DATA USED IN TABLE 4-1 AND IN CALCULATIONS SHOWN IN APPENDIX C

(1) Actual cubic meters - stack conditions
(2) Dry normal cubic meters - 20°C, 760 mm Hg
(3) Actual cubic feet - stack conditions
(4) Dry standard cubic feet - 20°C, 760 mm Hg
(5) Actual cubic meters per second - stack conditions
(6) Dry normal cubic meters per second - 20°C, 760 mm Hg
(7) Actual cubic feet per minute - stack conditions
(8) Dry standard cubic feet per minute - 20°C, 760 mm Hg
(9) Metric tons per hour (1 metric ton = 1000 kg)

* EPA Method 5

7

TABLE I

SUMMARY OF PARTICULATE* EMISSIONS

J.M. Brenner Company
Lancaster, Pennsylvania
November 19-22, 1974

Sampled Source: Inlet C Dimensions: 9-1/2" I.D.

Test Number		1	2
Date		11-21	11-22
Sampling Period	Start	09:00	11:28
	Stop	12:27	15:30
Sampled Volume	Am^3 (1)	2.539	2.533
	DNm^3 (2)	2.537	2.579
	ACF (3)	89.66	89.44
	DSCF (4)	89.58	91.05
Percent Moisture by Volume		0.6	0.6
Average Stack Temperature	°C	4.4	5.6
	°F	40	42
Stack Gas Flowrate	Am^3/sec (5)	0.524	0.519
	DNm^3/sec (6)	0.524	0.529
	ACFM (7)	1110	1100
	DSCFM (8)	1110	1120
Percent Isokinetic		101.8	96.7
Feed Rate	M tons/hr (9)	108	115
	tons/hr	119	127
Sample Weight (mg)		1102.4	1407.4
Particulate Concentration	mg/Am^3	434	556
	mg/DNm^3	435	546
	gr/ACF	0.190	0.243
	gr/DSCF	0.190	0.239
Particulate Emission Rate	kg/hr	0.82	1.0
	kg/M ton of feed	0.008	0.009
	lb/hr	1.8	2.3
	lb/ton of feed	0.02	0.02

DATA USED IN TABLE 4-1 AND IN CALCULATIONS SHOWN IN APPENDIX C

(1) Actual cubic meters - stack conditions
(2) Dry normal cubic meters - 20°C, 760 mm Hg
(3) Actual cubic feet - stack conditions
(4) Dry standard cubic feet - 20°C, 760 mm Hg
(5) Actual cubic meters per second - stack conditions
(6) Dry normal cubic meters per second - 20°C, 760 mm Hg
(7) Actual cubic feet per minute - stack conditions
(8) Dry standard cubic feet per minute - 20°C, 760 mm Hg
(9) Metric tons per hour (1 metric ton = 1000 kg)

TABLE I

SUMMARY OF PARTICULATE* EMISSIONS

J.M. Brenner Company
Lancaster, Pennsylvania
November 19-22, 1974

Sampled Source: Inlet D Dimensions: 18" I.D.

Test Number		1	2
Date		11-21	11-22
Sampling Period	Start	12:02	13:50
	Stop	09:06	11:14
Sampled Volume	Am^3 (1)	2.513	2.376
	DNm^3 (2)	2.507	2.406
	ACF (3)	88.74	83.91
	DSCF (4)	88.54	84.97
Percent Moisture by Volume		1.2	1.1
Average Stack Temperature	°C	2.8	5.0
	°F	37	41
Stack Gas Flowrate	Am^3/sec (5)	3.65	3.46
	DNm^3/sec (6)	3.66	3.52
	ACFM (7)	7740	7340
	DSCFM (8)	7750	7460
Percent Isokinetic		96.6	[illegible]6.4
Feed Rate	M tons/hr (9)	108	115
	tons/hr	119	127
Sample Weight (mg)		6.0	13635.2
Particulate Concentration	mg/Am^3	2.4	5740
	mg/DNm^3	2.4	5670
	gr/ACF	0.001	2.51
	gr/DSCF	0.001	2.48
Particulate Emission Rate	kg/hr	0.03	71.8
	kg/M ton of feed	0.0003	0.62
	lb/hr	0.07	158
	lb/ton of feed	0.0006	1.2

DATA USED IN TABLE 4-1 AND IN CALCULATIONS SHOWN IN APPENDIX C

(1) Actual cubic meters - stack conditions
(2) Dry normal cubic meters - 20°C, 760 mm Hg
(3) Actual cubic feet - stack conditions
(4) Dry standard cubic feet - 20°C, 760 mm Hg
(5) Actual cubic meters per second - stack conditions
(6) Dry normal cubic meters per second - 20°C, 760 mm Hg
(7) Actual cubic feet per minute - stack conditions
(8) Dry standard cubic feet per minute - 20°C, 760 mm Hg
(9) Metric tons per hour (1 metric ton = 1000 kg)

Excerpts from

REFERENCE 23 (SECTION 4.0)

Stack Sampling Report of Official Air Pollution Emission Tests Conducted on Kiln No. 1 at J. E. Baker Company, Millersville, OH, Princeton Chemical Research, Inc., Princeton, NJ, March 1975.

SUMMARY

The unit being tested is aninclined rotary kiln, fired with crushed coal. The particulate emission from this operation is controlled by a venturi scrubber.

Mr. K. Cherry, of the NW District Office of OEPA, was notified of our intent to test the unit. Our sampling technique was described to him. A modification was requested for sampling at the inlet duct. This modification was discussed with Mr. Cherry and accepted by him provided the liquid catch be included in the results. The liquid catch was included.

Standard gravimetric analyses, as described below, were used to determine the weight of particulate matter collected in each sample.

The analytical results wereas follows:

Location	Test #	lb./hr.
Inlet	1	3412.*
	2	5210.*
	3	3202.*
	Avg.	$\boxed{3941.}$ – 246 lb/ton product
Outlet	4	37.51
	5	37.74
	6	36.37
	Avg.	$\boxed{37.21}$ – 2.3 lb/ton product
Apparent Efficiency		99.06%

The conclusion drawn from the above data is that the Kiln #1 at J. E. Baker Co., Millersville, Ohio is in compliance with the air code of the State of Ohio.

* These results contain both the wet and dry catch.

DATA USED IN TEXT FOR REFERENCE 23 AND CALCULATIONS SHOWN IN APPENDIX C

STACK SAMPLING MEASUREMENTS - PARTICULATES

Run No.	241-P-1-I
Date	2-27-75
Time	1155

Sampling Data:	
Probe Size (inches)	1/4
Sample Period (minutes)	72
Number of Sampling Points (total)	12
Sample Volume (ACF @ stack)*	187.84
Sample Volume (SCFD)**	72.22
% of Isokinetic Flow Rate	91.6
Barometric Pressure ("Hg)	29.36
Sampling Technique	EPA #5

Emissions Data:	gr/SCFD	lb./hr.
Impinger Collections		
Insolubles	4.160	2891.31
H_2O Solubles	0.750	521.08
Total Particulates	4.910	3412.39

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

* Actual cubic feet @ stack temperature, pressure and humidity.
** Dry standard cubic feet (@ 70°F).

STACK SAMPLING MEASUREMENTS - PARTICULATES

Run No.	~~241-P-2-1~~
Date	2-27-75
Time	1500
Sampling Data:	
Probe Size (inches)	1/4
Sample Period (minutes)	72
Number of Sampling Points (total)	12
Sample Volume (ACF @ stack)*	160.47
Sample Volume (SCFD)**	60.72
% of Isokinetic Flow Rate	105.7
Barometric Pressure ("Hg)	29.36
Sampling Technique	EPA #5

Emissions Data:	gr/SCFD	lb./hr.
Impinger Collections		
Insolubles	9.430	4781.80
H_2O Solubles	0.844	428.21
$\boxed{\text{Total Particulates}}$	10.274	5210.01

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

* Actual cubic feet @ stack temperature, pressure and humidity.
** Dry standard cubic feet (@ 70°F).

STACK SAMPLING MEASUREMENTS - PARTICULATES

Run No.	241-P-3-I
Date	2-27-75
Time	1750

Sampling Data:

Probe Size (inches)	1/4
Sample Period (minutes)	72
Number of Sampling Points (total)	12
Sample Volume (ACF @ stack)*	115.44
Sample Volume (SCFD)**	41.55
% of Isokinetic Flow Rate	93.1
Barometric Pressure ("Hg)	29.36
Sampling Technique	EPA #5

Emissions Data:

	gr/SCFD	lb./hr.
Impinger Collections		
Insolubles	7.314	2879.69
H_2O Solubles	0.819	322.39
Total Particulates	8.133	3202.08

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

* Actual cubic feet @ stack temperature, pressure and humidity.
** Dry standard cubic feet (@ 70°F).

STACK SAMPLING MEASUREMENTS - PARTICULATES

Run No.	241-P-4-0
Date	2-28-75
Time	1500

Sampling Data:

Probe Size (inches)	1/4
Sampling Period (minutes)	72
Number of Sampling Points (total)	24
Sample volume (ACF @ Stack)*	59.29
Sample volume (SCFD)**	49.39
% of Isokinetic rate	110.0
Barometric Pressure ("Hg)	28.95
Sampling Technique	EPA #5

Emissions Data:

	gr/SCFD(Total)	lb./hr.		
		Filter	Impinger	Total
Filter and Impinger Collections, Insoluble	0.063	31.76	5.75	37.51

15

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

* Actual cubic feet @ stack temperature, pressure and humidity.
** Dry standard cubic feet (@ 70°F).

STACK SAMPLING MEASUREMENTS - PARTICULATES

Run No.	241-P-5-0
Date	2-28-75
Time	1800

Sampling Data:

Probe Size (inches)	1/4
Sampling Period (minutes)	72
Number of Sampling Points (total)	24
Sample volume (ACF @ Stack)*	56.40
Sample volume (SCFD)**	48.50
% of Isokinetic rate	109.4
Barometric Pressure ("Hg)	28.95
Sampling Technique	EPA #5

Emissions Data:

	gr/SCFD(Total)	lb./hr. Filter	lb./hr. Impinger	lb./hr. Total
Filter and Impinger Collections, Insoluble	0.264	33.70	3.97	37.74

117

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

* Actual cubic feet @ stack temperature, pressure and humidity.
** Dry standard cubic feet (@ 70°F)

STACK SAMPLING MEASUREMENTS - PARTICULATES

Run No.	241-P-6-0
Date	2-28-75
Time	1945

Sampling Data:

Probe Size (inches)	1/4
Sampling Period (minutes)	72
Number of Sampling Points (total)	24
Sample volume (ACF @ Stack)*	64.63
Sample volume (SCFD)**	55.52
% of Isokinetic rate	108.4
Barometric Pressure ("Hg)	28.95
Sampling Technique	EPA #5

Emissions Data:

		lb./hr.		
	gr/SCFD(Total)	Filter	Impinger	Total
Filter and Impinger Collections, Insoluble	0.053	$\boxed{35.60}$	0.77	36.37

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

* Actual cubic feet @ stack temperature, pressure and humidity.
** Dry standard cubic feet (@ 70°F).

									30	80					
									99	95		77			

OHIO KILN NO. 1 DATE [illegible]

Venturi DIFF	ID FAN AMPS	KILN AMPS	PRESS. Hood	PRESS. Feed	COOLER AIR FLOW	COOLER AIR LOCK	COOLER FAN PRESS.	COOLER FAN AMPS	#2 MILL AMPS / BOWL MILL AMPS	MILL DIFF. / BOWL MILL INLET PRESS	PRI. TEMP. / BOWL MILL INLET TEMP.	FAN TEMP. / BOWL MILL EXIT TEMP.	HOOD TEMP.	% OX/CON	% CONV
[illegible].5	390	110	0	.8	3.7	-.06	3.0	65	145	.6	360	145	18.5		
15.0	390	105	-10	.8	3.4	-.08	2.0	65	140	.7	350	[illegible]	19.4		
15.0	390	130	-.10	.9	3.2	-.08	1.6	62	145	.6	350	145	19.9		
15.0	390	125	-.10	.8	3.5	-.08	2.0	65	145	.6	350.	150	19.7		
15.0	390	130	-.10	.8	3.5	-.06	2.0	65	145	.6	350	145	20.6		
15.0	390	130	-.07	.7	3.1	-.06	2.2	66	150	.6	350	145	19.9		
15.0	390	110	0	.7	3.0	-.08	2.5	62	142	.6	350	[illegible]	19.4		
15.0	350	140	-.03	.7	2.8	-.12	2.0	60	155	.6	350	145	19.4		
15.0	390	[illegible]	-.04	.7	2.9	-.06	2.2	60	150	.6	360	145	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	.4	[illegible]	[illegible]	[illegible]	60	145	.6	[illegible]	[illegible]	[illegible]		
15.0	[illegible]	[illegible]	0	.5	2.8	-.08	1.5	60	145	.6	350	140			
15.0	390	130	0	.8	3.0	-.06	1.5	60	155	.6	360	142	19.6		
15.0	390	130	0	.8	3.2	+.03	1.5	60	140	.6	310	140	19.0		
15.0	390	125	-.05	.7	2.9	0	1.5	60	150	.6	[illegible]	140	19.0		
15.0	385	130	-.05	.8	3.0	+.04	1.5	60	140	.6	360	143	19.4		
14.5	380	115	-.10	.9	2.8	+.04	1.5	60	138	.6	370	140	19.4		
14.5	380	115	-.04	.9	3.0	+.02	2.0	60	140	.5	360	140	19.3		
14.5	390	110	-.05	.9	3.0	-.06	1.5	60	135	.6	360	144	20.0		
14.5	380	115	-.05	.9	3.0	+.04	2.0	60	145	.6	360	144	19.1		
14.5	390	140	-.05	.9	3.0	0	2.0	60	137	.6	350	142	19.7		
15.0	380	125	-.05	.9	3.0	+.04	1.5	60	138	.6	350	140	19.7		
[illegible]	390	115	0	.9	3.0	+.10	1.5	60	138	.6	350	140	19.5		
15.0	380	120	0	.9	3.0	-.02	1.5	60	[illegible]	.6	360	142	18.0		
15.0	375	110	-.03	.9	3.0	-.02	2.0	60	135	.6	360	142	19.5		
14.5	380	[illegible]	0	.9	3.0	-.02	2.0	60	138	.6	350	140	20.5		

(2-3) KILN TURNS 308 | FEED CONV. 37795 | IRON COAL 855 | (8-4) KILN TURNS 301

[illegible] 7-22 [illegible] 12:30, Gas [illegible] 12:15
[illegible] full
[illegible] 70 [illegible] 5:30 12 - [illegible]
[illegible] 3 - [illegible]
[illegible]

[illegible]
[illegible]
[illegible]
15 [illegible]

[illegible] Weight [illegible]
Coal 3.7136 Ton/Hour feed
Stone 28.52 Ton/Hour

CAR NUMBER TICKET	CUSTOMER	BINS	TONS	INT.	TICKET
[illegible]	[illegible]	5-6BCD	95	2.2	89699
[illegible]	[illegible]	8-7?-C	95	2.2	89698
[illegible]	[illegible]	9-6BCD		3.5	89700

LOST 0 - 9

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	77	75	73	77	[illegible]	[illegible]		
[illegible]					48	46		43		14		
[illegible]					2.7	31						
[illegible]					E	E						

OHIO KILN NO. 1 DATE 2-28-[illegible]

TIME	Venturi DIFF	ID FAN AMPS	KILN AMPS	PRESS. Hood	PRESS. Feed	COOLER AIR FLOW	COOLER AIR LOCK	COOLER FAN PRESS.	COOLER FAN AMPS	[illegible]	#2 MILL AMPS / BOWL MILL AMPS	MILL DIFF. / BOWL MILL INLET PRESS	PRI. TEMP. / BOWL MILL INLET TEMP.	FAN TEMP. / BOWL MILL EXH. TEMP.	HOOD TEMP.	% OXYGEN	KING VALV / % CONV
AM																	
	14.5	[illegible]	110	0	.9	3.0	-.02	2.0	60		1.38	.6	350	140	20.5		
	14.5	375	135	0	.9	3.0	-.0	2.5	60		1.37	.6	320	140	19.[illegible]		
2	15.0	375	135	0	.9	3.0	0	2.5	60		1.35	.6	340	125	18.7		
	15.0	375	135	0	.9	3.0	0	2.0	60		1.35	.6	300	120	18.6		
4	15.0	375	135	0	.9	3.0	0	2.5	60		1.35	.6	290	125	18.[illegible]		
	15.0	375	135	0	.8	3.1	-.02	2.5	60		1.32	.6	300	127	18.5		
	15.0	375	135	0	.8	3.0	-.02	2.0	58		1.35	.6	290	130	18.9		
7	15.0	375	135	0	.8	3.0	-.02	2.0	60		1.35	.6	290	130	18.8		
	15.0	375	[illegible]25	0	.8	3.0	-.02	2.0	60		1.30	.6	340	125	19.0		
	15.0	380	[illegible]	1.0		3.0	-.06	2.0	58		1.30	.6	310	134	17.5		
9	14.5	380	135	0	1.0	3.1	-.08	2.0	60		1.30	.6	300	130	18.5		
	15.0	[illegible]	135	0	1.0	3.0	-.06	2.0	60		1.30	.6	[illegible]	130	17.[illegible]		
	14.5	380	135	0	1.0	3.3	-.10	2.0	60		1.30	.6	290	130	17.8		
12PM	15.0	380	120	0	1.0	3.2	-.08	2.0	60		1.30	.6	330	140	18.6		
	14.5	370	115	0	.9	3.0	-.06	1.5	58		1.30	.6	330	135	19.6		
	15.0	375	115	0	.9	3.0	-.04	1.5	60		1.30	.6	330	135	19.7		
	15.0	375	115	0	1.0	3.0	-.04	1.0	60		1.35	.6	310	135	20.0		
	14.5	375	115	0	.9	3.0	-.04	1.5	60		1.35	.6	290	134	19.0		
	15.0	375	135	-.05	1.0	3.0	-.02	1.0	60		1.35	.6	310	135	20.5		
	14.5	375	120	0	.9	3.0	-.04	1.0	60		1.32	.6	300	135	21.0		
	14.5	375	120	0	.9	3.0	-.02	1.5	60		1.3[illegible]	.6	[illegible]	[illegible]	[illegible]		
	15.0	390	110	0	.9	3.0	-.04	1.5	60		1.30	.6	310	135	22.[illegible]		
	15.0	370	120	0	.9	3.0	-.02	1.0	60		1.35	.6	300	135	22.5		
	15.0	370	105	0	.9	3.0	-.08	1.0	60		1.30	.6	300	138	22.0		
2AM	15.0	370	[illegible]	0	.9	3.0	-.06	1.5	60		1.30	.6	290	135	22.0		

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

KILN TURNS 1564 | FEED CONV. [illegible] | IRON CONV. [illegible] | (8-4) KILN TURNS 2057

[illegible] cooler pit. [illegible] 60 [illegible]
[illegible] Cooler pit [illegible] kiln [illegible]
[illegible] cooler to [illegible]
[illegible] S.W. [illegible] N.W. [illegible]
[illegible] #121 [illegible]

Turned S.E. [illegible]
Cleaned [illegible]
[illegible]
1st 2nd [illegible]
[illegible]
2 [illegible]

CAR TICKET	NUMBER	CUSTOMER	BINS		INT.
[illegible]	[illegible]86165	[illegible]	7B+20, [illegible]	25	[illegible]
[illegible]	216565	[illegible]	9 [illegible]	25	PB

CAR TICKET	NUMBER	
89710		[illegible]
89711		[illegible]
89712		[illegible]

Product weights [illegible]
Coal – 3.579 T/hr.
Stone – 28.92 T/hr.

Excerpts from

REFERENCE 24 (SECTION 4.0)

Feairheller, W. R., and T. L. Peltier, Air Pollution Emission Test, Virginia Lime Company, Ripplemead, VA, EPA Contract No. 68-02-1,404 (Office of Air Quality and Standards), Monsanto Research Corporation, Dayton, OH, April/May 1975.

Table 1

SUMMARY OF PARTICULATE RESULTS

	4/30/75		5/01/75		5/02/75		5/03/75		5/03/75	
Run Number	1		2		3		4		5	
Vol. of gas sampled (DSCF-Nm^3)[a]	11.80	.334	19.59	.555	26.01	.736	23.71	.671	26.72	.757
% Moisture by volume	6.60	6.60	2.73	2.73	3.75	3.75	4.74	4.74	4.76	4.76
Average stack temp. (°F-°C)	403	206	392	200	388	198	394	201	395	202
Stack Volumetric Flow Rate (DSCFM-Nm^3/sec)[b]	45515	21.5	61090	28.8	59260	28.0	53432	25.2	55795	26.3
Stack Volumetric Flow Rate (ACFM-m^3/sec)[c]	84753	40.0	107751	50.9	105183	49.6	96796	45.7	101189	47.8
% Isokinetic	98.8	98.8	90.5	90.5	92.9	92.9	94.0	94.0	101.4	101.4
Duration of run-minutes	26.7	26.7	36	36	48	48	48	48	48	48
Limestone Feed Rate (Ton/hr-metric ton/hr)	23	20.9	28	25.4	29	26.3	27	24.5	29	26.3
Particulates-probe, cyclone and filter catch										
mg	8944.1	8944.1	11072.5	11072.5	19586.7	19586.7	13125.0	13125.0	15864.7	15864.7
(grain/DSCF-gm/Nm^3)[d]	11.6765	26.72	8.7061	19.92	11.5965	26.54	8.5239	19.51	9.1422	20.92
(lb/hr-kg/hr)	4554.6	2065.9	4558.0	2067.5	5889.4	2671.4	3903.2	1770.5	4371.4	1982.8
Particulates-total catch										
mg					19727.1	19727.1	13180.5	13180.5	15938.2	15938.2
(grains/DSCF-gm/Nm^3)					11.6797	26.73	8.5599	19.59	9.1845	21.02
(lb/hr-kg/hr)					5931.5	2690.5	3919.7	1777.9	4391.19	1992.0
Percent impinger catch					0.7	0.7	0.4	0.4	0.5	0.5
Emission Factor										
lb/Ton-kg/mTon (Product)	396	197.6	325.6	162.8	409.1	204.6	290.3	145.2	302.8	151.4
lb/Ton-kg/mTon (Feed)	198	98.8	163	81.4	205	102.3	145	72.6	151	75.7

CORRECTED FOR IMPINGER CATCH -- SEE CALCULATIONS IN APPENDIX C

a - Dry standard cubic feet @ 70°F, 29.92 in Hg - normal cubic meters at 21.1°C, 760 mm Hg

b - Dry standard cubic feet per minute - normal cubic meters per second

c - Actual cubic feet per min., stack conditions - actual cubic meters per second

d - Grains per dry standard cubic feet - mg per normal cubic meters

DATA USED IN TABLE 4-1 AND IN CALCULATIONS SHOWN IN APPENDIX C

TABLE 7

Brink® Particle Sizing

Run #1 - 5/02/75

Stage	Weight of Material	DPC	mg/ACF	Weight PCNT	Cumulative Weight PCNT
Cyclone	67.300		91.88	96.46	100.00
1	0.45	2.77	.62	.65	3.55
2	0.46	1.62	.63	.66	2.90
3	0.10	1.10	.14	.15	2.24
4	0.12	0.56	.17	.18	2.10
5	0.14	0.34	.20	.21	1.93
Filter	1.20		1.64	1.72	1.72

Run #2 - 5/03/75

Stage	Weight of Material	DPC	mg/ACF	Weight PCNT	Cumulative Weight PCNT
Cyclone	66.70		121.96	97.09	100.00
1	.59	1.96	1.08	.86	2.92
2	.14	1.13	.26	.21	2.06
3	.21	.75	.39	.31	1.85
4	.10	.36	.19	.15	1.55
5	.06	.18	.11	.09	1.40
Filter	.90		1.65	1.32	1.32

DATA REPRODUCED IN TABLE 4-2

Excerpts from

REFERENCE 25 (SECTION 4.0)

Maurice, R. L., and P. F. Allard, Stack Emissions Analysis, U. S. Lime Plant, Nelson, AZ, Engineers Testing Laboratories, Inc., Phoenix, AZ, May 1975.

ENGINEERS TESTING LABORATORIES, INC.
2525 E. INDIAN SCHOOL ROAD
PHOENIX, ARIZONA 85016
(602) 957-9050

KENNEDY VAN SAUN CORPORATION
DANVILLE, PENNSYLVANIA 17821

21 MAY 1975

ATTENTION: BRUCE MOWERY

SUBJECT: STACK EMISSIONS ANALYSIS AT THE FLINTCOTE LIME PLANT OF NELSON, AZ

JOB NO. 543-193
P.O.NO. 359777
LAB NO. 40-2257

RESULTS ARE ENCLOSED OF THE STACK EMISSIONS ANALYSIS PERFORMED AT THE U. S. LIME PLANT AT NELSON, ARIZONA ON MAY 6 AND 7, 1975.

PARTICULATE EMISSIONS

TEST NUMBER 1 .... 36 LBS PER HR. PARTICULATES
TEST NUMBER 2 .... 37 LBS PER HR. PARTICULATES
TEST NUMBER 3 .... 35 LBS PER HR. PARTICULATES

SULFUR REMOVAL

APPARENT SULFUR REMOVAL 93%

THE STATE OF ARIZONA EMISSIONS STANDARDS ALLOW A PARTICULATE EMISSIONS RATE OF 46 LBS/HR. FOR THE RAW STONE FEED RATE OF 61 TONS PER HOUR AND REQUIRE A MINIMUM SULFUR REMOVAL OF 90%.

RESPECTFULLY SUBMITTED,
ENGINEERS TESTING LABORATORIES, INC.

BY: R.L. Maurice AND PFAllard
ROBERT L. MAURICE, JR. PETER F. ALLARD, P. E.

/JM

COPIES TO: ADDRESSEE (6)
BUREAU OF AIR POLLUTION CONTROL (1)
ATTN: CARL MERCER
FLINTKOTE COMPANY (1)/WM.W.MC CANDLISH

DATA USED IN TEXT FOR REFERENCE 25 AND IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

REFERENCE 26 (SECTION 4.0)

Stack Sampling Report of Official Air Pollution Emission Tests Conducted on Kiln No. 2 Scrubber at J. E. Baker Company, Millersville, OH, Princeton Chemical Research, Inc., Princeton, NJ, May 1975.

SUMMARY OF RESULTS

Test #	1	2	3	Avg.
Particulate, lb/hr				
Found	69.41	129.14	47.28	81.94
Allowable	34.46	34.46	34.46	34.46
Sulfur Oxides, as SO_2, ppmv				
Found	471	397	514	461
Allowable	2000	2000	2000	2000

The above data indicate that the scrubber stack from Kiln #2 is not in compliance with Ohio Air Pollution Regulation EP-11-11.

The stack is in compliance with Ohio Air Pollution Regulation EP-11-12 (Sulfur Dioxide).

DATA USED IN TEXT FOR REFERENCE 26 AND IN CALCULATIONS SHOWN IN APPENDIX C

2.57	51	151	264	.2
[illegible]	16	150	264	251

OHIO KILN NO. 2 DATE [illegible]

Diff	ID Fan Amps	Kiln Amps	Press. Hood	Press. Feed	Cooler Air Flow	Cooler Air Lock	Cooler Fan Press.	Cooler Fan Amps	Bowl Mill Exh. Press	#2 Mill Amps / Bowl Mill Amps	Mill Diff. / Bowl Mill Inlet Press	Pri. Temp. / Bowl Mill Inlet Temp.	Fan Temp. / Bowl Mill Exh. Temp.	Hood Temp.	% Oxygen
					[illegible]	[illegible]	[illegible]								
7.8	280	[illegible] 150	+04	.5	0	5.7	[illegible]		1.6	105		[illegible]	[illegible]		[illegible]
8.2	280	135	+04	.4	0	5.8	1260		1.6	108		510	158		.11
8.0	[illegible]	135	+01	[illegible]	-.02	5.9	1400		1.9	108		[illegible]	[illegible]		[illegible]
8.7	280	135	+04	.3	+.02	6.6	1240		1.3	108		500	118		.9
8.2	280	135	+04	.3	+.06	6.4	1220		1.3	108		525	180		.4
8.0	280	135	+04	.4	+.08	6.4	1140		1.3	108		550	154		.7
7.8	280	135	+04	.4	0	6.0	1390		1.3	108		525	180		.7
7.9	280	135	+04	.7	0	6.2	1440		1.2	108		500	178		.5
8.0	280	135	+04	.4	+.04	6.2	1400		1.4	108		550	156		.5
9.0	275	135 180	+.04	.4	+.09	6.2	1240		1.5	108		550	154		1.1
8.9	275	135 180	+.07	.3	[illegible]	6.2	1310		1.7	[illegible]		550	160		.5
8.7	275	135 180	+.03	.2	+.18	6.0	1260		1.1	108		500	181		.4
8.4	275	135 180	+.03	.3	+.18	5.9	1330		1.3	108		500	175		.7
8.0	272	135 180	+.03	.3	+.10	5.9	1410		1.2	108		500	180		1.2
8.6	275	135 180	+.05	.4	+.08	6.2	1320		1.1	108		[illegible]	181		.7
8.6	275	135 190	+.04	.4	+.02	6.2	1290		1.2	108		475	184		1.7
8.1	275	135 [illegible]	[illegible]	.3	+.15	6.1	[illegible]		1.1	108		475	[illegible]		[illegible]
8.0	279	135 180	+.04	.3	+.06	6.0	1340		.8	108		430	192		.5
7.6	279	135 180	+.05	.3	+.10	5.9	1290		.8	108		320	194		.6
8.0	279	135 180	+.02	.4	+.08	6.0	1320		1.0	108		360	185		.7
8.6	279	135 180	0	.2	+.08	6.2	1300		1.4	108		500	158		.1
7.6	279	135 180	+.04	.2	+.06	6.3	1280		1.4	108		500	158		.7
7.5	279	135 180	+.05	.2	+.06	6.3	1360		1.2	108		500	110		.5
7.8	280	135 180	+.04	.3	+.08	6.2	1400		1.1	108		500	183		.6
8.5	280	135 180	+.04	.3	+.08	6.3	1400		.9	108		450	186		.5

KILN TURNS 27388 FEED CONV. 6431500. IRON CONV. 1103570 (8-4) KILN TURNS 27700

[illegible] *523-[illegible]

[illegible]

T/Hr [illegible]

20.073 Stone 963500 #/24h

3.066 coal 109000 #/24hr 1.35

.037 IRON 40260 #/24h

23.978 = Σ = 46365 #/hr

4-Loads [illegible]

8-Buckets [illegible]

4 Buckets [illegible]

*4 Bin full 10:30 [illegible]

Car Ticket	Number	Customer	Bins	Tons	Int.
	coal: ~~5[illegible]~~	Million BTU/hr			
	79.701	13000 BTU/#			

Car Ticket	Number
[illegible]	
714C-272045	

[illegible] LBS./FT. IRON [illegible] LBS./FT. LOST TIME 0 HRS. 0 MIN. STONE ____ LBS./FT.

Excerpts from

<u>REFERENCE 27 (SECTION 4.0)</u>

Crowell, D., et al., Test conducted at Marblehead Lime Company, Bellefonte, PA, Report on the Particulate Emissions from a Lime Kiln Baghouse, Marblehead Lime Company, Chicago, IL, July 1975.

II. SUMMARY RESULTS

The two baghouse stacks tested are both divided into six sections. At the request of the Commonwealth of Pennsylvania Department of Environmental Resources corresponding sections (section 1) from Baghouse "A" and "B" were tested on the first day. On the next day a second set of tests were conducted in a similar manner on different sections (section 4).

Results of the four runs are reported below according to Pennsylvania Sampling - Testing Rules in pounds per hour and are compared with allowable mass emission rates for all three process kilns.

	Mass Rate of Emissions Pounds per Hour	Allowable Emissions Pounds per Hour
Baghouse "A" Section 1	2.8	
Baghouse "B" Section 1	2.5	
Subtotal	5.3	
Total Emission from both Baghouses (Subtotal x 6 identical compartments)	31.8	56.8
Baghouse "A" Section 4	2.0	
Baghouse "B" Section 4	3.0	
Subtotal	5.0	
Total Emissions from both Baghouses (Subtotal x 6 identical compartments)	30.0	58.9

avg = 30.9

Average Emission Rate Both Baghouses	30.9 Pounds/Hour

from both baghouse

Average Allowable Emission Rate 57.9 Pounds/Hour

30.9 lb/hr

DATA USED IN TEXT FOR REFERENCE 27 AND IN CALCULATIONS SHOWN IN APPENDIX C

IV. PRODUCTION SUMMARY:

PRODUCTION IN TONS PER HOUR

7/17		Kiln #1	Kiln #2	Kiln #3
Baghouse A Section 1	11:00 AM	9.8	10.3	11.2
	12:00 PM	12.3	12.4	8.3
	1:00 PM	12.2	11.1	8.1
Baghouse B Section 1	4:00 PM	10.5	8.2	13.0
	5:00 PM	11.3	9.5	9.1
	6:00 PM	12.4	7.6	12.5
	Total	68.5	59.1	62.2
	Average	11.4	9.9	10.4

Allowable Emission = .76 (200#/ton x ton/hr. Pro

$$\text{Kiln \#1} = .76\ (200 \times 11.4)^{.42} = 19.55$$
$$\text{Kiln \#2} = .76\ (200 \times 9.9)^{.42} = 18.43$$
$$\text{Kiln \#3} = .76\ (200 \times 10.4)^{.42} = 18.81$$

Total Allowable 3 Sources = 56.79

7/18		Kiln #1	Kiln #2	Kiln #3
Baghouse B Section 4	10:00 AM	12.2	11.7	12.2
	11:00 AM	12.3	11.1	12.2
	12:00 PM	12.3	11.2	12.2
Baghouse A Section 4	3:00 PM	12.3	10.7	13.0
	4:00 PM	12.0	8.0	12.5
	5:00 PM	12.2	7.5	12.5
	Total	73.3	60.2	74.6
	Average	12.2	10.0	12.4

Allowable Emission Rate = .76 (200#/ton x ton/hour

$$\text{Kiln \#1} = .76\ (200 \times 12.2)^{.42} = 20.11$$
$$\text{Kiln \#2} = .76\ (200 \times 10.0)^{.42} = 18.50$$
$$\text{Kiln \#3} = .76\ (200 \times 12.4)^{.42} = 20.25$$

Total allowable 3 Sources = 58.86

DATA USED IN TEXT FOR REFERENCE 27 AND IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

REFERENCE 28 (SECTION 4.0)

Peltier, T.L., Air Pollution Emission Test, Martin-Marietta Corporation, Calera, AL, EMB Project No. 76-LIM-9, U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, September 1975.

Table 2. SUMMARY OF PARTICULATE EMISSIONS FROM THE BAGHOUSE (ENGLISH)

Run Number	1-1	2-2	1-2	3-1	3-2	2-3	Average[b]
Date	9-9-75	9-10-75	9-10-75	9-10-75	9-11-75	9-12-75	
Volume of gas sampled - dscf[a]	67.00	82.44	78.82	85.75	85.75	70.51	
Percent moisture by volume	4.45	11.87	11.60	14.71	11.22	9.25	
Average stack temp. - °F	267	288	261	294	278	233	
Stack volumetric flow rate							
dscfm	9809	10356	10379	10649	11115	9513	
Percent Isokinetic	96.3	112.2	111.2	117.9	115.6	108.5	
Run time - minutes	132	132	132	132	132	132	
Particulates - front half							
mg	42.90	21.2	31.4	27.4	40.8	15.2	89.5
grains/dscf	0.0099	0.004	0.0061	0.0049	0.0072	0.0033	0.0177
lb/hr	0.829	0.351	0.546	0.449	0.632	0.271	1.564
Particulates - total							
mg	74.30	39.7	54.2	68.6	72.4	33.3	171.3
grains/dscf	0.0171	0.0074	0.0106	0.0123	0.0127	0.0073	0.0337
lb/hr	1.436	0.658	0.942	1.124	1.210	0.593	2.982
Percent impinger catch	42.3	46.7	42.0	60.1	43.6	54.3	47.6
Process Emission Rate							
lb/ton Feed	0.0415	0.0176	0.0273	0.0235	0.0341	0.0181	0.0811

[a]Dry standard cubic feet @ 70°F, 29.92 in Hg

[b]The average is for all 3 stacks combined

DATA USED IN TABLE 4-1

Table 1. SUMMARY OF PARTICULATE EMISSIONS FROM THE BAGHOUSE (METRIC)

ST. No.	1	2	1	3	3	2	
Run No.	1	2	2	1	2	2	
Run Number	1-1	2-2	1-2	3-1	3-2	2-3	Average[b]
Date	9-9-75	9-10-75	9-10-75	9-10-75	9-11-75	9-12-75	
Volume of Gas Sampled							
Nm³[a]	1.90	2.33	2.23	2.43	2.48	2.00	
Percent moisture by volume	4.45	11.87	11.60	14.71	11.22	9.25	
Average stack temp. - °C	131	142	127	146	137	112	
Stack volumetric flow rate							
Nm³/min	278	293	294	302	315	269	
Percent Isokinetic	96.3	112.2	111.2	117.9	115.6	108.5	
Run Time - Minutes	132	132	132	132	132	132	
Particulates - Front half							
mg	42.9	21.2	31.4	27.4	40.8	15.2	39.5
mg/Nm³	22.8	9.1	14.1	11.3	16.5	7.6	40.7
Kg/hr	0.377	0.160	0.248	0.204	0.311	0.123	0.692
Particulates - Total							
mg	74.3	39.7	54.2	68.6	72.4	33.3	171.3
mg/Nm³	39.1	17.0	24.3	28.2	29.2	16.7	77.3
Kg/hr	0.65[illegible]	[illegible]	[illegible]	[illegible]	0.552	[illegible]	1.357
Percent Impinger Catch	42.3	46.7	42.0	60.1	43.6	54.3	47.6
Process Emission Rate							
Kg/ton Feed	[illegible]	[illegible]	0.0137	0.0118	0.0171	0.0099	$\boxed{0.0406}$

a) Normal cubic meters at 21.1°C, 760 mm Hg

b) The average is for all 3 stacks combined

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Table 9. SUMMARY OF PARTICULATE EMISSIONS FROM THE HYDRATOR (ENGLISH)

Run Number	1	2	3	Average
Date	9-12-75	9-17-75	9-17-75	
Volume of Gas Sampled - dscf	37.65	54.52	50.97	47.67
Percent Moisture	79.09	75.71	79.04	77.95
Average Stack Temp. - °F	201	200	203	201
Stack Volumetric Flow Rate - dscf/min	1207	1576	1232	1338
Percent Isokinetic	89.4	99.1	118.5	
Run Time - Minutes	128	128	128	128
Particulates - Front half				
mg	278.6	509.5	980.4	589.5
grains/dscf	0.1139	0.1439	0.2962	0.1847
lb/hr	1.179	1.944	3.128	2.084
Particulates - Total				
mg	322.7	526.3	1025.2	624.7
grains/dscf	0.1320	0.1487	0.3097	0.1968
lb/hr	1.365	2.008	3.271	2.215
Percent Impinger Catch	13.6	3.2	4.4	6.0

DATA IN TABLE 4-1 CALCULATED FOR TESTS #1-3 USING PROCESS DATA IN TABLE 11 OF REPORT

DATA USED IN TABLE 4-1

Table 8. SUMMARY OF PARTICULATE EMISSIONS FROM THE HYDRATOR (METRIC)

Run Number	1	2	3	Average
Date	9-12-75	9-17-75	9-17-75	
Volume of Gas Sampled - Nm^3	1.07	1.54	1.44	1.35
Percent Moisture	79.09	75.71	79.04	77.95
Average Stack Temp. - °C	93.9	93.3	95.0	94.1
Stack Volumetric Flow Rate - Nm^3/min	34.18	44.63	34.89	37.90
Percent Isokinetic	89.4	99.1	118.5	
Run Time - Minutes	128	128	128	128
Particulates - Front half				
mg	278.6	509.5	980.4	589.5
mg/Nm^3	260.4	330.8	680.8	424.0
Kg/hr	0.534	0.886	1.425	0.943
Particulates - Total				
mg	322.7	526.3	1025.2	624.7
mg/Nm^3	301.6	341.8	711.9	451.8
Kg/hr	0.618	0.915	1.490	1.008
Percent Impinger Catch	13.6	3.2	4.4	6.0

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

separating processes in the lime plant. Visible emissions were evident from many of these collectors, but no sampling of these emissions was done. On the third particulate test, the filter had to be changed three times due to excessive loading, but this did not appear to be abnormal.

According to the Martin Marietta operator and the EPA process data, the hydrator was operating normally during the testing. The process data are given in Appendix F and are summarized in Table 11.

Table 11. MARTIN-MARIETTA HYDRATOR PROCESS DATA

Date (1975)	Lime Feedrate (TPH)[a]	Water to Scrubber (GPM)[b]	Water to Hydrator (GPM)[b]	Hydrator Temp. (°F)
12 Sept.	18	20	13.5	206
17 Sept.	17.2	19	15.2	195
17 Sept.	18	19	16.4	196

[a]Ton per hour

[b]Gallon per minute

DATA USED IN TABLE 4-1 AND IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

<u>REFERENCE 29 (SECTION 4.0)</u>

Peltier, T.A., et al., Air Pollution Emission Test, Allied Products Company, Montevallo, AL, EPA Contract No. 68-02-1404, Task 20, (EPA, Office of Air Quality Planning and Standards), Monsanto Research Corporation, Dayton, OH, September 1975.

Table 2. SUMMARY OF PARTICULATE EMISSIONS (English)

Run Number	1	2	3	Average
Date	9-15-75	9-16-75	9-16-75	
Volume of Gas Sampled - dscf	61.14	61.18	58.69	60.34
Percent Moisture by Volume	19.86	18.77	20.91	19.85
Average Stack Temperature - °F	148	147	151	149
Stack Volumetric Flow Rate - dscfm	97037	97021	91216	95091
Percent Isokinetic	100.5	100.5	102.6	
Run Time - Minutes	120	120	120	120
Particulates - Front Half				
mg	119.30	85.20	121.30	108.60
gr/dscf	0.0300	0.0214	0.0318	0.0277
lb/hr	24.977	17.824	24.870	22.557
USING STONE FEED RATE OF 51.6 TPH EMISSION FACTORS ARE:	0.484	, 0.345	, 0.482 LB/TON FEED	
Particulates - Total				
mg	131.90	93.00	131.30	118.74
gr/dscf	0.0332	0.0234	0.0345	0.0304
lb/hr	27.615	19.456	26.921	24.664
Percent Impinger Catch	9.6	8.4	7.6	8.5

DATA USED IN TABLE 4-1

Table 1. SUMMARY OF PARTICULATE EMISSIONS (Metric)

Run Number	1	2	3	Average
Date	9-15-75	9-16-75	9-16-75	
Volume of Gas Sampled - Nm^3	1.73	1.73	1.66	1.71
Percent Moisture by Volume	19.86	18.77	20.91	19.85
Average Stack Temperature - °C	64	64	66	65
Stack Volumetric Flow Rate - Nm^3/min	2748	2747	2583	2693
Percent Isokinetic	100.5	100.5	102.6	
Run Time - Minutes	120	120	120	120
Particulates - Front Half				
mg	119.30	85.20	121.30	108.60
mg/Nm^3	68.8	49.1	72.9	63.6
Kg/hr	11.330	8.085	11.281	10.232
Particulates - Total				
mg	131.90	93.00	131.30	118.74
mg/Nm^3	76.0	53.6	78.9	69.5
Kg/hr	12.526	8.825	12.211	11.187
Percent Impinger Catch	9.5	8.4	7.6	8.5

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Table 7. SUMMARY OF BRINKS® PARTICLE SIZING RESULTS (METRIC) USING UNIT DENSITY

CASCADE IMPACTOR PARTICLE SIZE DISTRIBUTION FOR RUN 1

INPUT VARIABLE	UNITS	INPUT DAT.
SAMPLING TIME	MIN	10.0
PRESSURE DROP	CM HG	3.30
STATIC PRESSURE	CM H2O	-10.80
PARTICLE DENSITY	G/CC	1.00
BAROMETRIC PRESSURE	CM HG	75.77
GAS MOL WT		28.0
GAS TEMPERATURE	DEG C	90.4
GAS VISCOSITY	POISE	0.00022
GAS DENSITY	G/CC	0.00095

STAGE	WT OF MATERIAL	DPC	MG/ACM	WT PCNT	CUM WT PCNT
CYCLONE	85.000		3.73	87.89	100.00
1	8.366	4.63	0.36	8.57	12.11
2	0.915	2.73	0.04	0.94	3.55
3	1.000	1.87	0.04	1.02	2.61
4	0.240	0.90	0.01	0.25	1.58
5	0.206	0.61	0.01	0.21	1.34
FILTER	1.100		0.05	1.13	1.13

CASCADE IMPACTOR PARTICLE SIZE DISTRIBUTION FOR RUN 2

INPUT VARIABLE	UNITS	INPUT DATA
SAMPLING TIME	MIN	4.0
PRESSURE DROP	CM HG	2.03
STATIC PRESSURE	CM H2O	-15.62
PARTICLE DENSITY	G/CC	1.00
BAROMETRIC PRESSURE	CM HG	75.49
GAS MOL WT		28.0
GAS TEMPERATURE	DEG C	86.7
GAS VISCOSITY	POISE	0.00021
GAS DENSITY	G/CC	0.00096

STAGE	WT OF MATERIAL	DPC	MG/ACM	WT PCNT	CUM WT PCNT
CYCLONE	70.000		9.56	94.07	100.00
1	2.060	5.06	0.28	2.74	5.93
2	1.210	3.00	0.16	1.61	3.19
3	0.490	2.05	0.07	0.65	1.58
4	0.150	1.09	0.02	0.20	0.93
5	0.150	0.70	0.02	0.20	0.73
FILTER	0.400		0.05	0.55	0.53

CASCADE IMPACTOR PARTICLE SIZE DISTRIBUTION FOR RUN 3

INPUT VARIABLE	UNITS	INPUT DATA
SAMPLING TIME	MIN	4.0
PRESSURE DROP	CM HG	2.79
STATIC PRESSURE	CM H2O	-16.54
PARTICLE DENSITY	G/CC	1.00
BAROMETRIC PRESSURE	CM HG	75.23
GAS MOL WT		28.1
GAS TEMPERATURE	DEG C	93.3
GAS VISCOSITY	POISE	0.00022
GAS DENSITY	G/CC	0.00094

STAGE	WT OF MATERIAL	DPC	MG/ACM	WT PCNT	CUM WT PCNT
CYCLONE	73.000		8.59	93.91	100.00
1	2.431	4.79	0.20	3.09	6.09
2	1.004	2.63	0.17	1.28	2.99
3	0.137	1.94	0.02	0.17	1.72
4	0.120	1.02	0.01	0.15	1.54
5	0.092	0.64	0.01	0.12	1.39
FILTER	1.000		0.17	1.27	1.27

DATA REPRODUCED IN TABLE 4-3

Table 13. SUMMARY OF LIME KILN OPERATING DATA TAKEN DURING SAMPLING

Test	Date (1975)	Limestone Feed Rate (TPH)	Fuel (Coal) Feed Rate (TPH)	Fuel (Gas) Feed Rate (1000 CFM)	Stack Temp. °F	Oxygen %
1	9/15	51.6	6.7	15	345	0.5
2	9/16	51.6	6.5	15	340	0.5
3	9/16	51.6	5.9	34	340	0.5

DATA USED IN TABLE 4-1 AND IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

REFERENCE 32 (SECTION 4.0)

Feairheller, W.R., et al., Source Test of a Lime Plant, Standard Lime Company, Woodville, OH, EPA Contract No. 68-02-1404, Task 12, (EPA, Office of Air Quality Planning and Standards), Monsanto Research Corporation, Dayton, OH, December 1975.

Table 2. SUMMARY OF PARTICULATE EMISSIONS FROM KILNS 4 AND 6 (ENGLISH)

	Kiln 4[c]			Kiln 6[d]		
Run Number - Kiln Number	1-4	2-4	Average	1-6	2-6	Average
Date	12-9-75	12-9-75		12-10-75	12-10-75	
Volume of Gas Sampled - DSCF[a]	44.43	44.67	44.55	34.36	26.25	30.31
Percent Moisture by Volume	6.00	2.36	4.18	3.60	3.35	3.48
Average Stack Temperature - °F	388	384	386	526	533	530
Stack Volumetric Flow Rate - DSCFM	58825	58218	58522	53366	39299	46333
Percent Isokinetic	91.7	93.1	92.4	98.1	101.8	100.0
Run Time - minutes	60	60	60	72	72	72
Particulates - Front Half						
mg	17751	5624		11964	11278	
g/DSCF	6.153	1.939	4.046	5.362	6.616	5.989
lb/hr	3102	967	2035	2452	2228	2340
Particulates - Total						
mg	17760	5635		11995	11344	
g/DSCF	6.156	1.943	4.050	5.377	6.655	6.015
lb/hr	3104	969	2037	2459	2241	2350
Percent Impinger Catch	0.05	0.20	0.125	0.26	0.58	0.42
Limestone Feed Rate - ton/hr	55.6	59.6	57.6	30.0	30.0	30.0
Production Rate - ton/hr	24.0	25.8	24.7	11.5	11.5	11.5
Emission Factor (b) - lb/ton (feed)	55.8	16.2	36.0	82.0	74.7	78.4
lb/ton (Product)	129.3	37.6	83.5	213.3	194.9	204.4

a) Dry standard cubic feet at 68°F, 29.92 in Hg
b) Front half data only
c) Emission data collected after multiclone and preheater
d) Emission data after low efficiency cyclone

DATA USED IN TABLE 4-1

Table 1. SUMMARY OF PARTICULATE EMISSIONS FROM KILNS 4 AND 6 (METRIC)

	Kiln 4[c]			Kiln 6[d]		
Run Number - Kiln Number	1-4	2-4	Average	1-6	2-6	Average
Date	12-9-75	12-9-75		12-10-75	12-10-75	
Volume of Gas Sampled - Nm^3 [a]	1.262	1.269	1.265	0.976	0.746	.851
Percent Moisture by Volume	6.00	2.36	4.18	3.60	3.35	3.48
Average Stack Temperature - °C	198	196	197	274	279	277
Stack Volumetric Flow Rate - Nm^3/min	1666	1649	1658	1511	1113	1312
Percent Isokinetic	91.7	93.1	92.4	98.1	101.8	100.0
Run Time - minutes	60	60	60	72	72	72
Particulates - Front Half						
mg	17751	5624		11964	11278	
g/Nm^3	14.084	4.438	9.261	12.274	15.144	13.709
Kg/hr	1407	439	923	1112	1011	1062
Particulates - Total						
mg	17760	5635		11995	11344	
g/Nm^3	14.091	4.447	9.269	12.306	15.233	13.770
Kg/hr	1408	440	924	1115	1017	1066
Percent Impinger Catch	0.05	0.20	0.125	0.26	0.58	0.420
Limestone Feed Rate - metric ton/hr	50.4	54.1	52.3	27.2	27.2	27.2
Production Rate - metric ton/hr	21.8	23.4	22.6	10.4	10.4	10.4
Emission Factor (b) - kg/mTon (feed)	27.9	8.1	18.0	41.0	37.[illegible]	39.2
kg/mTon (Product)	64.6	18.8	41.7	107.[illegible]	97.[illegible]	102.5

a) Normal cubic meters at 20°C
~~b) Front half data only~~
c) Emission data collected after multiclone and preheater
d) Emission data after low efficiency cyclone

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Table 4. BRINK® PARTICLE SIZING

Kiln 4 - 12-9-75

Stage	Weight of Material (mg)	DPC[a]	MG/ACF[b]	Wt. %	Cum. Wt. %
Cyclone	60.600		175.35	60.73	100.00
1	21.100	2.30	61.005	21.14	39.28
2	9.100	1.26	26.33	9.12	18.14
3	2.900	0.79	8.39	2.91	9.02
4	2.800	0.32	8.10	2.81	6.11
5	2.600	0.16	7.52	2.61	3.31
Filter	0.700		2.03	0.70	0.70

Kiln 6 - 12-9-75

Stage	Weight of Material (mg)	DPC[a]	MG/ACF[b]	Wt. %	Cum. Wt. %
Cyclone	88.400		409.67	78.84	100.00
1	7.360	3.09	34.11	6.56	21.16
2	9.220	1.70	42.73	8.22	14.59
3	1.460	1.07	6.77	1.30	6.37
4	1.230	0.45	5.70	1.10	5.07
5	3.650	0.23	16.92	3.26	3.97
Filter	0.800		3.71	0.71	0.71

DATA REPRODUCED IN TABLE 4-4

(a) Characteristic cut point diameter of particles collected (micrometers)

(b) MG/ACF - milligram per actual cubic foot

Excerpts from

REFERENCE 36 (SECTION 4.0)

Doumas, A.C., et al., Industrial Process Profiles for Environmental Use, Chapter 18, The Lime Industry, EPA-600/2-77-023r (NTIS PB 281485), U.S. Environmental Protection Agency, Cincinnati, OH, February 1977.

Hydration/Packing

1. Function - Hydrated lime (calcium hydroxide) is manufactured in this process step by slowly adding water to ground quicklime in predetermined proportions from process step 5 in a hydrator or slaker. Both batch and continuous hydrators are employed. Mechanical agitation is used to insure thorough mixing. Continuous hydrators are steadily replacing batch units. Some lime dust is emitted from the stack of the hydrator. This dust is recovered in a washer-scrubber collector and the resulting milk of lime is recycled directly to the hydrator or its pre-mix chamber. In this way, valuable lime is recovered and air emissions from this source are minimized.

   Normally hydrated dolomitic lime consists of calcium hydroxide and magnesium oxide with little if any magnesium hydroxide. However, dolime can be completely hydrated in an autoclave under pressure.

   Closed circuit conveyors are used for transporting the semiprocessed hydrate from the hydrator to the finishing part of the process. This is done to prevent recarbonation of the hydrated lime. Usually a system of horizontal screw conveyors and bucket elevators are employed.

   Any uncalcined lime, overburned material or silica in the hydrated products is removed in an air separator after the hydration step is completed. Centrifugal air separators are universally employed in the final milling and classification of the product.

   Finished dry hydrate product is transported to product silos and from there to bagging machines.

   Some hydration of lime is also carried out with great excess of water so that a slurry of "milk of lime" solution is produced instead of a dry powder. This process is usually called slaking. Slaking equipment is usually located at the plant site of the user. Only in cases where the lime producer has a captive use for slaked lime will a slaker be employed at the lime plant proper.

2. Input Materials

   Quantities are based on one metric ton of dry hydrated lime:

   - Quicklime: approximately 0.757 ton
   - Water: approximately 0.243 ton

   The above figures are theoretical quantities required to make a dry hydrated lime from pure quicklime. Generally a slight excess of water is added to offset losses from the steam formed and lost by the heat of hydration.

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

Excerpts from

REFERENCE 40 (SECTION 4.0)

Report on the Particulate Emissions from a Lime Kiln Baghouse (Exhibit 2 supplied by the National Lime Association), May 1977.

Plant Po-2 PARTICULATE

STACK TEST

#/ton Feed (allowable = 0.3 #/ton)

Run Number Date	1 5-4-77	2 5-5-77	3 5-6-77	4 5-7-77	5 5-9-77	6 5-10-77	AVG	TOTAL
olume Gas Sampled SCFD	53.155	55.581	48.116	55.685	63.977	49.574	53.348	326.098
Moisture, Volume	11.4	15.5	12.3	15.1	9.9	11.8	12.67	
verage Stack Temp. °F	404.0	428.0	420.5	420.5	426.5	371.3	411.80	
CFM D	11,862	11,707	10,812	11,218	13,782	10,705	11,681	70,086
CFM	21,829	23,378	20,302	22,560	25,309	18,852	22,038	132,230
Isokinetic	97.1	102.4	96.0	103.4	100.1	99.9	99.82	
eed Rate T/hr (Limestone only)	43.9	42.5	43.5	44.0	42.1	41.1	$\boxed{42.85}$	
oal Feed T/r	6.3	5.7	6.2	6.1	6.1	6.0	6.07	
otal MWH	50.2	48.2	49.7	50.1	48.2	47.1	48.92	
articulates - Probe & Filter Catch								
g	56.9	93.9	174.7	114.1	74.7	106.7	103.5	621.0
r/DSCF	0.0165	0.0261	0.0560	0.0316	0.0180	0.0332	0.0302	
/hr	1.65	2.65	5.09	3.15	2.13	3.04	2.95	$\boxed{17.71}$
/ton Feed .41	0.0376	0.0624	0.1170	0.0716	0.0506	0.0740	0.0689	
1.17 MHL, .46 #PA								
articulates - Total Catch								
g	411.0	201.7	203.6	132.2	217.6	131.4	216.3	1297.5
r/DSCF	0.1192	0.0560	0.0652	0.0366	0.0524	0.0409	0.0617	
/hr	11.96	5.69	5.93	3.64	6.21	3.75	6.20	37.18
/ton Feed	0.2724	0.1339	0.1363	0.0827	0.1475	0.0912	0.1440	
Impinger Catch	86.2	53.4	14.2	13.5	65.7	18.9	42.0	

Dated Cited in Section 4.1.12 and used in calculations shown in Appendix C

Excerpts from

REFERENCE 41 (SECTION 4.0)

Report on the Particulate Emissions from a Lime Kiln Baghouse (Exhibit 3 supplied by the National Lime Association), May 1977.

Plant #3 PARTICULATE

STACK TEST

Run Number / Date	1 / 5-24-77	2 / 5-25-77	3 / 5-26-77	AVG	AVERAGE X 6 STACKS
olume Gas Sampled, SCFD	54.655	49.233	54.339	52.742	
Moisture, Volume	14.0	15.4	13.9	14.4	
verage Stack Temp. °F	410.5	428.0	426.5	421.7	
CFM D	11,564	10,074	11,327	10,988	65,930
CFM	21,853	19,807	21,893	21,184	127,106
Isokinetic	101.9	105.4	103.5	103.6	
eed Rate T/hr (Limestone only)	46.23	53.52	46.58	48.78	
oal Feed T/hr	6.04	6.06	6.04	6.05	
otal PWR	52.27	59,58	52.62	54.82	
articulates - Probe & Filter Catch					
g	137.6	132.0	174.3	148.0	887.8
r/DSCF	0.0388	0.0413	0.0495	0.0432	
/hr	3.88	3.67	4.89	4.15	24.88
/ton feed	0.0839	0.0686	0.1050	0.0858	$\boxed{0.515}$
articulates - Total Catch					
g	144.2	145.5	203.4	164.4	986.2
r/DSCF	0.0407	0.0456	0.0577	0.0480	
/hr	4.08	4.05	5.70	4.61	27.66
/ton feed	0.0883	0.0757	0.1224	0.0955	0.5728
Impinger Catch	4.90	9.38	14.21	9.50	

Data cited in Section 4.1.13 and used in calculations shown in Appendix C

Excerpts from

REFERENCE 42 (SECTION 4.0)

Report on the Particulate Emissions from a Lime Kiln Baghouse (Exhibit 1 supplied by the National Lime Association), August 1977.

Plant No. 1

PARTICULATE STACK TEST

		EXISTING BAGS				NEW BAGS	
Baghouse-Section		B-1	A-4	B-4	A-1	A-4	A-4
Run Number		1	2	3	4	5	6
Date		8-09-77	8-09-77	8-11-77	8-11-77	8-12-77	8-12-77
olume Gas Sampled SCFD		53.010	49.073	59.166	43.865	62.486	56.211
Moisture, Volume		5.0	5.1	4.5	5.1	4.2	4.5
verage Stack Temp. °F		324	351	356	327	340	343
CFM D		12,630	11,610	13,550	10,174	14,720	12,930
CFM		19,590	18,640	21,720	15,810	23,110	20,460
Isokinetic		102.5	103.3	106.6	105.4	103.8	106.2
eed Rate T/hr (Limestone only)		25.8	25.4	23.1	20.6	23.6	24.1
oal Feed T/r	Avg.	4.1	4.0	3.7	3.3	3.8	3.8
otal PWR	3	29.9	29.4	26.8	23.9	27.4	27.9
ime Production	Kilns	13.7	13.5	12.2	10.9	12.5	12.8
articulates - Probe & Filter Catch							
g		176.1	319.4	283.7	126.0	126.6	148.4
g/DSCF		0.051	0.100	0.074	0.044	0.031	0.041
/hr		5.62	10.16	8.88	3.98	4.02	4.65
/ton feed		0.87	1.60	1.54	0.77	0.68	0.77
articulates - Total Catch							
g		256.5	360.8	321.2	182.3	151.9	174.2
g/DSCF		0.075	0.113	0.084	0.064	0.037	0.048
/hr		8.19	11.47	10.06	5.75	4.82	5.46
/ton feed		1.27	1.81	1.74	1.12	0.82	0.91
Impinger Catch		31.4	11.4	11.7	30.8	16.6	14.8

Data reproduced in Section 4.1.14 and used in calculations shown in Appendix C

Excerpts from

<u>REFERENCE 45 (SECTION 4.0)</u>

Cobb, G.R., et al., Characterization of Inhalable Particulate Matter Emissions from a Lime Plant, Vol. I, EPA-600/X-85-342a, Midwest Research Institute, Kansas City, MO, May 1983.

TABLE 3-4. IMPACTOR PARTICLE SIZE TEST SAMPLING DATA BAGHOUSE INLET AND OUTLET

Run No.	7 µm cyclone Mass (mg)[a]	7 µm cyclone D_{50} size (µm)[b]	7 µm cyclone Cum. % less than[c]	Stage 1 Mass (mg)	Stage 1 D_{50} size (µm)	Stage 1 Cum. % less than	Stage 2 Mass (mg)	Stage 2 D_{50} size (µm)	Stage 2 Cum. % less than	Stage 3 Mass (mg)	Stage 3 D_{50} size (µm)	Stage 3 Cum. % less than	Stage 4 Mass (mg)	Stage 4 D size (µm)	Stage 4 Cum. % less than
Bag-1-1-1	58.77	7.00	28.56	1.06	3.33	27.28	11.06	1.95	13.83	6.92	1.31	5.42	1.44	0.67	3.67
Bag-1-1-2	28.40	7.00	34.00	2.36	4.38	28.51	8.45	2.58	8.88	2.15	1.76	3.42	1.03	0.92	1.02
Bag-1-1-3	49.30	7.00	31.52	3.46	3.81	27.13	15.60	2.23	5.46	2.77	1.51	1.61	1.16	0.77	0.00
Bag-1-1-4	34.32	7.00	25.34	6.59	4.20	11.01	4.16	2.47	1.96	0.90	1.68	0.00	0.00	0.87	0.00
Bag-1-2-1	46.40	7.00	34.19	3.48	3.51	29.26	15.97	2.05	6.61	3.43	1.39	1.74	0.71	0.71	0.74
Bag-1-2-2(2)[d]	0.00	7.00	100.00	1.27	4.47	92.82	4.71	2.64	82.47	4.37	1.80	72.88	1.31	0.94	70.00
Bag-1-2-3(2)	50.57	7.00	29.81	11.28	3.57	14.15	6.47	2.09	5.17	1.98	1.41	2.41	0.90	0.72	1.16
Bag-1-2-4	38.16	7.00	33.41	2.39	4.48	29.24	8.35	2.64	14.67	7.44	1.80	1.69	0.67	0.94	0.52
Bag-1-3-1	33.47	7.00	33.93	7.99	3.16	18.15	5.82	1.85	6.66	1.91	1.25	2.88	0.83	0.63	1.23
Bag-1-3-2	25.70	7.00	43.17	1.81	3.93	39.16	9.04	2.31	19.17	7.28	1.56	3.07	0.88	0.81	1.13
Bag-1-3-3(2)	40.30	7.00	34.78	3.57	4.03	28.99	13.53	2.37	7.09	2.61	1.61	2.86	0.90	0.83	1.40
Bag-1-3-4	42.57	7.00	28.10	7.25	4.25	15.85	5.87	2.50	5.93	2.10	1.70	2.38	0.47	0.88	1.58
Bag-1-4-1	50.00	7.00	25.88	0.50	3.45	13.28	5.15	2.02	5.64	2.00	1.37	2.67	0.77	0.70	1.52
Bag-1-4-2	30.67	7.00	35.03	2.20	4.24	30.36	9.19	2.49	10.89	2.66	1.69	5.25	1.67	0.88	1.70
Bag-1-4-3	70.11	7.00	28.81	12.41	3.61	16.20	11.18	2.11	4.85	2.92	1.43	1.88	0.94	0.73	0.92
Bag-1-4-4(2)	23.10	7.00	33.35	4.39	4.35	20.67	4.60	2.56	7.39	1.98	1.74	1.67	0.50	0.91	0.21

Run No.	Stage 4 Mass (mg)	Stage 4 D_{50} size (µm)	Stage 4 Cum. % less than	Stage 5 Mass (mg)	Stage 5 D_{50} size (µm)	Stage 5 Cum. % less than	Filter Mass (mg)	Filter D_{50} size (µm)	Total mass (mg)
Bag-1-1-1	1.44	0.67	3.67	3.02	0.40	0.00	0.00	< 0.40	82.27
Bag-1-1-2	1.03	0.92	1.02	0.44	0.58	0.00	0.00	< 0.58	
Bag-1-1-3	1.16	0.77	0.00	0.00	0.47	0.00	0.00	< 0.47	
Bag-1-1-4	0.00	0.87	0.00	0.00	0.54	0.00	0.00	< 0.54	
Bag-1-2-1	0.71	0.71	0.74	0.52	0.42	0.00	0.00	< 0.42	
Bag-1-2-2(2)[d]	1.31	0.94	70.00	0.42	0.60	69.07	31.48	< 0.60	
Bag-1-2-3(2)	0.90	0.72	1.16	0.13	0.44	0.98	0.73	< 0.44	
Bag-1-2-4	0.67	0.94	0.52	0.29	0.59	0.02	0.01	< 0.59	
Bag-1-3-1	0.83	0.63	1.23	0.62	0.38	0.00	0.00	< 0.38	
Bag-1-3-2	0.88	0.81	1.13	0.45	0.50	0.13	0.06	< 0.50	
Bag-1-3-3(2)	0.90	0.83	1.40	0.86	0.52	0.00	0.00	< 0.52	
Bag-1-3-4	0.47	0.88	1.58	0.19	0.55	1.26	0.75	< 0.55	
Bag-1-4-1	0.77	0.70	1.52	0.61	0.42	0.61	0.41	< 0.42	
Bag-1-4-2	1.67	0.88	1.70	0.51	0.55	0.61	0.29	< 0.55	
Bag-1-4-3	0.94	0.73	0.92	0.09	0.45	0.83	0.82	< 0.45	
Bag-1-4-4(2)	0.50	0.91	0.21	0.07	0.57	0.00	0.00	< 0.57	

(continued)

DATA REPRODUCED IN TABLE 4-5

TABLE 3-4. (continued)

Run No.	15 µm cyclone Mass (mg)[a]	15 µm cyclone D_{50} size (µm)[b]	15 µm cyclone Cum. % less than[c]	Stage 0 Mass (mg)	Stage 0 D_{50} size (µm)	Stage 0 Cum. % less than	Stage 1 Mass (mg)	Stage 1 D_{50} size (µm)	Stage 1 Cum. % less than	Stage 2 Mass (mg)	Stage 2 D_{50} size (µm)	Stage 2 Cum. % less than	Stage 3 Mass (mg)	Stage 3 D_{50} size (µm)	Stage 3 Cum. % less than
Bag-0-1-1	4.47	15.16	20.29	0.00	15.16	20.29	0.06	9.45	19.15	0.00	6.40	19.15	0.12	4.35	16.95
Bag-0-1-2	0.19	16.06	86.08	0.20	15.94	71.45	0.00	9.94	71.45	0.00	6.73	71.45	0.23	4.57	54.66
Bag-0-1-3(2)	4.44	15.80	55.76	0.21	15.80	53.24	0.98	9.05	43.37	0.88	6.67	34.51	0.87	4.54	25.75
Bag-0-1-4	0.00	15.33	100.00	0.32	15.33	80.23	0.35	9.56	75.36	0.78	6.43	61.41	0.33	4.40	49.27
Bag-0-2-1	1.07	15.65	78.53	0.52	15.65	68.05	0.25	9.76	62.98	0.39	6.61	55.10	0.38	4.49	47.43
Bag-0-2-2(2)	0.00	16.34	100.00	1.28	16.24	88.28	1.13	10.13	77.94	1.15	6.86	67.41	1.31	4.66	55.42
Bag-0-2-3	14.89	15.31	20.07	0.50	15.31	17.37	0.41	9.55	15.15	0.43	6.46	12.82	0.53	4.39	9.96
Bag-0-2-4	0.00	15.25	100.00	0.71	15.25	87.50	0.50	9.50	72.01	0.38	6.43	63.19	0.49	4.37	51.84
Bag-0-3-1	0.38	16.13	96.54	1.15	16.08	85.94	0.87	10.03	77.93	1.33	6.79	65.63	1.25	4.61	54.15
Bag-0-3-2(2)	0.05	16.18	99.19	0.00	16.18	99.19	0.00	10.09	99.19	0.00	6.84	99.19	1.05	4.65	82.05
Bag-0-3-3	126.01	15.49	12.02	0.00	15.49	12.02	0.00	9.66	12.02	0.00	6.54	12.02	2.03	4.44	10.60
Bag-0-3-4	0.96	15.49	72.14	0.00	15.49	72.14	0.00	9.65	72.14	0.13	6.53	68.33	0.42	4.44	56.11
Bag-0-4-1(2)	1.33	15.59	84.95	0.40	15.59	80.41	0.27	9.72	77.34	0.69	6.58	69.52	0.99	4.47	58.30
Bag-0-4-2	0.08	16.87	99.39	2.13	16.61	84.08	1.65	10.36	72.21	1.46	7.01	61.72	1.55	4.77	50.58
Bag-0-4-3	1.65	15.54	87.68	1.02	15.54	80.05	0.76	9.69	74.37	1.14	6.56	65.84	1.01	4.46	58.29
Bag-0-4-4	1.65	15.84	76.82	0.66	15.84	67.54	0.20	9.88	64.71	0.55	6.69	56.97	0.93	4.55	43.89

Run No.	Stage 4 Mass (mg)	Stage 4 D_{50} size (µm)	Stage 4 Cum. % less than	Stage 5 Mass (mg)	Stage 5 D_{50} size (µm)	Stage 5 Cum. % less than	Stage 6 Mass (mg)	Stage 6 D_{50} size (µm)	Stage 6 Cum. % less than	Stage 7 Mass (mg)	Stage 7 D_{50} size (µm)	Stage 7 Cum. % less than	Filter Mass (mg)	Filter D_{50} size (µm)
Bag-0-1-1	0.36	2.78	10.47	0.44	1.37	2.56	0.14	0.83	0.00	0.00	0.55	0.00	0.00	< 0.55
Bag-0-1-2	0.20	2.93	40.04	0.47	1.45	6.01	0.08	0.88	0.00	0.00	0.59	0.00	0.00	< 0.59
Bag-0-1-3(2)	0.87	2.90	16.99	1.23	1.44	4.62	0.27	0.87	1.89	0.04	0.58	1.47	0.15	< 0.58
Bag-0-1-4	0.37	2.81	35.68	0.68	1.39	10.82	0.18	0.84	4.14	0.11	0.56	0.00	0.00	< 0.56
Bag-0-2-1	0.72	2.87	32.95	0.83	1.42	16.28	0.49	0.86	6.40	0.10	0.57	4.33	0.22	< 0.57
Bag-0-2-2(2)	1.75	2.98	39.41	1.76	1.48	23.30	1.23	0.90	12.04	0.90	0.60	3.80	0.42	< 0.60
Bag-0-2-3	0.53	2.81	7.09	0.74	1.39	3.10	0.35	0.84	1.20	0.22	0.56	0.00	0.00	< 0.56
Bag-0-2-4	0.68	2.79	36.12	0.74	1.38	19.02	0.47	0.83	8.13	0.35	0.55	0.00	0.00	< 0.55
Bag-0-3-1	1.71	2.95	38.39	1.68	1.46	22.90	1.12	0.89	12.58	0.91	0.59	4.19	0.45	< 0.59
Bag-0-3-2(2)	1.92	2.98	50.74	2.23	1.48	14.54	0.57	0.90	5.23	0.32	0.61	0.00	0.00	< 0.61
Bag-0-3-3	3.99	2.84	7.81	7.71	1.40	2.43	3.14	0.85	0.23	0.33	0.57	0.00	0.00	< 0.57
Bag-0-3-4	0.65	2.84	37.21	1.16	1.40	3.52	0.12	0.85	0.00	0.00	0.56	0.00	0.00	< 0.56
Bag-0-4-1(2)	1.34	2.86	43.12	1.67	1.41	24.21	0.49	0.86	18.65	0.15	0.57	16.94	1.50	< 0.57
Bag-0-4-2	1.89	3.05	36.99	1.85	1.51	23.69	1.48	0.92	13.05	1.09	0.61	5.21	0.73	< 0.61
Bag-0-4-3	1.57	2.85	46.56	2.57	1.41	27.35	2.00	0.85	12.41	1.66	0.57	0.00	0.00	< 0.57
Bag-0-4-4	1.18	2.91	27.10	1.46	1.44	6.78	0.41	0.88	1.00	0.07	0.59	0.00	0.00	< 0.59

[a] mg = milligrams

[b] µm = micrometers

[c] Cum. % = cumulative percent less than stated D_{50} size

[d] Not used in calculations due to suspect stage loading

DATA REPRODUCED IN TABLE 4-6

TABLE 3-6. IMPACTOR PARTICLE SIZE TEST SAMPLING DATA ELECTROSTATIC PRECIPITATOR INLET AND OUTLET

Run No.	7 µm cyclone Mass (mg)[a]	7 µm cyclone D_{50} size (µm)[b]	7 µm cyclone Cum. % less than[c]	Stage 1 Mass (mg)	Stage 1 D_{50} size (µm)	Stage 1 Cum. % less than	Stage 2 Mass (mg)	Stage 2 D_{50} size (µm)	Stage 2 Cum. % less than	Stage 3 Mass (mg)	Stage 3 D_{50} size (µm)	Stage 3 Cum. % less than
ESP-1-1-1	244.42	7.00	5.80	9.31	3.93	2.21	2.80	2.29	1.13	0.94	1.55	0.77
ESP-1-1-2	205.03	7.00	5.49	6.52	4.00	2.48	3.24	2.34	0.99	0.58	1.58	0.72
ESP-1-1-3(2)	284.14	7.00	5.64	9.83	4.14	2.37	3.51	2.41	1.21	1.10	1.63	0.84
ESP-1-1-4(2)	295.16	7.00	4.89	8.21	4.56	2.24	4.29	2.67	0.86	1.19	1.81	0.48
ESP-1-2-1	144.85	7.00	11.21	12.61	4.16	3.48	4.27	2.43	0.86	0.74	1.64	0.40
ESP-1-2-2	212.54	7.00	6.93	9.82	4.00	2.63	3.17	2.34	1.24	0.82	1.58	0.88
ESP-1-2-3	237.04	7.00	5.68	8.59	4.26	2.27	2.94	2.49	1.19	0.77	1.68	0.79
ESP-1-2-4	392.14	7.00	8.05	25.03	4.11	2.18	6.06	2.40	0.75	1.48	1.62	0.41
ESP-1-3-1	297.77	7.00	5.47	11.38	4.23	1.85	3.39	2.47	0.77	0.76	1.67	0.53
ESP-1-3-2	221.67	7.00	6.69	10.14	4.09	2.42	4.14	2.39	0.67	0.88	1.62	0.30
ESP-1-3-3	231.96	7.00	5.25	8.62	4.11	1.73	3.12	2.40	0.46	0.50	1.62	0.25
ESP-1-3-4	383.07	7.00	5.02	14.67	3.84	1.39	3.48	2.24	0.52	0.90	1.51	0.10
ESP-1-4-1	236.77	7.00	6.07	9.64	4.24	2.24	3.21	2.48	0.97	0.87	1.67	0.62
ESP-1-4-2(2)	281.92	7.00	5.61	4.65	4.19	4.06	10.77	2.45	0.45	0.68	1.66	0.22
ESP-1-4-3	252.63	7.00	5.99	10.60	4.16	2.04	3.96	2.43	0.57	0.90	1.64	0.23
ESP-1-4-4	352.38	7.00	6.39	14.92	3.88	2.42	6.00	2.26	0.83	1.15	1.52	0.52

Run No.	Stage 4 Mass (mg)	Stage 4 D_{50} size (µm)	Stage 4 Cum. % less than	Stage 5 Mass (mg)	Stage 5 D_{50} size (µm)	Stage 5 Cum. % less than	Filter Mass (mg)	Filter D_{50} size (µm)
ESP-1-1-1	0.47	0.78	0.59	0.31	0.47	0.47	1.28	< 0.47
ESP-1-1-2	0.20	0.81	0.63	0.27	0.49	0.50	1.08	< 0.49
ESP-1-1-3(2)	0.73	0.83	0.60	0.47	0.50	0.44	1.32	< 0.50
ESP-1-1-4(2)	0.57	0.93	0.29	0.75	0.57	0.05	0.15	< 0.57
ESP-1-2-1	0.36	0.84	0.18	0.13	0.51	0.10	0.16	< 0.51
ESP-1-2-2	0.26	0.80	0.77	0.65	0.49	0.48	1.10	< 0.49
ESP-1-2-3	0.19	0.86	0.71	0.67	0.52	0.44	1.11	< 0.52
ESP-1-2-4	0.80	0.82	0.22	0.93	0.49	0.00	0.00	< 0.49
ESP-1-3-1	0.27	0.85	0.45	0.34	0.52	0.34	1.07	< 0.52
ESP-1-3-2	0.28	0.83	0.18	0.08	0.50	0.15	0.36	< 0.50
ESP-1-3-3	0.14	0.82	0.19	0.36	0.50	0.05	0.11	< 0.50
ESP-1-3-4	0.31	0.76	0.22	0.30	0.45	0.15	0.59	< 0.45
ESP-1-4-1	0.41	0.85	0.46	0.30	0.52	0.34	0.85	< 0.52
ESP-1-4-2(2)	0.21	0.85	0.15	0.12	0.52	0.11	0.33	< 0.52
ESP-1-4-3	0.47	0.84	0.05	0.00	0.51	0.05	0.14	< 0.51
ESP-1-4-4	0.57	0.76	0.37	0.90	0.45	0.13	0.50	< 0.65

(continued)

DATA REPRODUCED IN TABLE 4-7

TABLE 3-6. (continued)

Run No.	15 μm cyclone Mass (mg)[a]	15 μm cyclone D_{50} size (μm)[b]	15 μm cyclone Cum. % less than[c]	Stage 0 Mass (mg)	Stage 0 D_{50} size (μm)	Stage 0 Cum. % less than	Stage 1 Mass (mg)	Stage 1 D_{50} size (μm)	Stage 1 Cum. % less than	Stage 2 Mass (mg)	Stage 2 D_{50} size (μm)	Stage 2 Cum. % less than
ESP-0-1-1(2)	64.13	12.97	33.47	1.67	12.64	31.73	1.94	7.86	29.72	8.34	5.30	21.07
ESP-0-1-2(2)	25.14	13.40	96.20	5.28	12.98	59.06	1.94	8.07	56.45	6.79	5.45	41.31
ESP-0-1-3	47.63	12.61	49.35	1.43	12.36	47.87	3.10	7.68	44.53	13.85	5.18	29.80
ESP-0-1-4	17.67	12.75	67.49	1.53	12.45	64.68	2.17	7.74	60.68	8.95	5.22	44.21
ESP-0-2-1	56.27	13.11	41.51	4.94	12.78	36.38	2.36	7.90	33.92	8.31	5.33	25.29
ESP-0-2-2	23.58	15.32	61.93	6.73	14.45	51.06	3.62	9.00	45.21	7.73	6.08	32.73
ESP-0-2-3	114.26	14.95	34.76	2.12	14.14	33.55	2.17	8.80	32.31	13.62	5.94	24.53
ESP-0-2-4	29.84	13.53	55.74	1.36	13.13	53.73	1.99	8.17	50.77	9.74	5.51	36.32
ESP-0-3-1	44.65	13.13	59.58	5.38	12.72	54.70	4.68	7.91	50.47	12.88	5.34	38.80
ESP-0-3-2	22.21	16.04	62.28	0.84	13.48	60.85	1.60	8.39	58.14	7.06	5.66	46.14
ESP-0-3-3	34.02	15.30	49.00	2.66	14.44	45.07	1.36	8.99	42.98	6.92	6.07	32.60
ESP-0-3-4	17.02	15.02	65.98	1.85	14.22	62.29	1.12	8.85	60.05	5.27	5.98	49.53
ESP-0-4-1	64.23	13.43	49.67	3.67	12.90	46.79	6.18	8.02	41.95	17.47	5.41	28.26
ESP-0-4-2	14.33	14.01	74.49	1.92	13.40	71.07	2.95	8.34	65.81	10.58	5.63	46.97
ESP-0-4-3	63.35	16.74	27.28	0.91	15.43	86.30	1.20	9.60	25.00	4.98	6.49	19.63
ESP-0-4-4(2)	18.96	15.81	54.31	0.43	14.82	53.27	0.38	9.21	52.36	3.55	6.23	43.80

(continued)

DATA REPRODUCED IN TABLE 4-8

TABLE 3-6. (continued)

Run No.	Stage 3 Mass (mg)[a]	Stage 3 D_{50} size (µm)[b]	Stage 3 Cum. % less than[c]	Stage 4 Mass (mg)	Stage 4 D_{50} size (µm)	Stage 4 Cum. % less than	Stage 5 Mass (mg)	Stage 5 D_{50} size (µm)	Stage 5 Cum. % less than	Stage 6 Mass (mg)	Stage 6 D_{50} size (µm)	Stage 6 Cum. % less than
ESP-0-1-1(2)	7.16	3.59	13.64	6.21	2.28	7.20	3.97	1.10	3.08	1.22	0.65	1.81
ESP-0-1-2(2)	15.78	3.69	26.07	5.46	2.34	18.72	4.20	1.13	13.06	3.31	0.67	8.61
ESP-0-1-3	10.88	3.51	18.23	8.03	2.22	9.69	4.61	1.07	4.79	1.32	0.63	3.39
ESP-0-1-4	8.96	3.53	27.72	6.88	2.24	15.06	3.80	1.08	8.07	1.10	0.64	6.05
ESP-0-2-1	8.29	3.61	16.67	6.48	2.29	9.93	3.41	1.31	6.39	1.35	0.65	4.98
ESP-0-2-2	6.92	4.12	21.55	6.51	2.62	11.04	3.99	1.28	4.59	1.61	0.76	1.99
ESP-0-2-3	11.26	4.03	18.10	15.03	2.56	9.52	10.06	1.25	3.78	2.21	0.74	2.52
ESP-0-2-4	9.53	3.73	22.19	8.24	2.37	9.96	4.43	1.15	3.39	0.86	0.68	2.11
ESP-0-3-1	12.89	3.61	27.13	10.90	2.29	17.26	9.53	1.11	8.63	2.59	0.65	6.29
ESP-0-3-2	7.72	3.83	33.03	8.64	2.44	18.35	6.12	1.18	7.96	1.51	0.70	5.39
ESP-0-3-3	6.90	4.11	22.26	6.39	2.62	12.68	5.10	1.27	5.03	1.19	0.76	3.25
ESP-0-3-4	7.06	4.05	35.40	6.82	2.58	21.76	5.57	1.25	10.63	2.03	0.75	6.57
ESP-0-4-1	12.99	3.66	18.08	12.54	2.32	8.26	5.51	1.12	3.94	1.50	0.66	2.76
ESP-0-4-2	8.92	3.81	31.09	7.70	2.42	17.37	4.95	1.17	8.56	1.39	0.69	6.08
ESP-0-4-3	5.21	4.40	14.00	5.25	2.80	8.33	4.06	1.37	3.95	1.03	0.82	2.83
ESP-0-4-4(2)	4.71	4.23	32.45	6.85	2.69	15.94	5.06	1.31	3.74	1.40	0.78	0.36

Run No.	Stage 7 Mass (mg)	Stage 7 D_{50} size (µm)	Stage 7 Cum. % less than	Filter Mass (mg)	Filter D_{50} size (µm)
ESP-0-1-1(2)	0.83	0.41	0.95	0.92	< 0.41
ESP-0-1-2(2)	3.96	0.43	3.28	2.43	< 0.43
ESP-0-1-3	1.63	0.40	1.65	1.56	< 0.40
ESP-0-1-4	1.69	0.41	2.94	1.60	< 0.41
ESP-0-2-1	1.73	0.42	3.19	3.07	< 0.42
ESP-0-2-2	0.78	0.49	0.73	0.45	< 0.49
ESP-0-2-3	0.70	0.48	2.12	3.70	< 0.48
ESP-0-2-4	0.48	0.44	1.40	0.94	< 0.44
ESP-0-3-1	2.44	0.42	4.08	4.51	< 0.42
ESP-0-3-2	0.85	0.45	3.95	2.33	< 0.45
ESP-0-3-3	0.55	0.49	4.42	1.62	< 0.49
ESP-0-3-4	1.22	0.48	4.13	2.06	< 0.48
ESP-0-4-1	1.32	0.42	1.73	2.20	< 0.42
ESP-0-4-2	1.34	0.45	3.70	2.08	< 0.45
ESP-0-4-3	0.69	0.53	2.09	1.93	< 0.53
ESP-0-4-4(2)	0.15	0.51	0.00	0.00	< 0.51

[a] mg = net weight milligrams.

[b] D_{50} size = 50% effective cutoff diameter micrometers.

[c] Cum. % less than = cumulative percent less than stated size.

DATA REPRODUCED IN TABLE 4-8

TABLE 3-11. SUMMARY OF TEST RESULTS FOR RUN S-1

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions: ft³/min	Air flow rate[a] standard conditions: ℓ/min	Concentration of particulate matter measured by sampler (µg/m³)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/impactor stages (µmA): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	-	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	248,024	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	-	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	165,970	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	365,468	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	-	-	-	-	-	-	-	-	-	-
CI-2		X	2.5	5	20	566.3	495,333	-	-	342,081	49,808	63,540	23,721	10,201	3,971	2,009
CI-3		X	4	5	20	566.3	614,826	-	-	347,185	10,484	30,728	43,066	105,123	24,677	3;562

a Standard conditions = 25°C and 760 mm Hg.

b - indicates no data directly available.

c Cyclone catch

d Backup filter.

DATA REPRODUCED IN TABLE 4-9

TABLE 3-12. SUMMARY OF TEST RESULTS FOR RUN S-2

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions: ft^3/min	Air flow rate[a] standard conditions: ℓ/min	Concentration of particulate matter measured by sampler ($\mu g/m^3$)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/Impactor stages (μmA): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	-	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	299,257	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	-	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	372,466	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	351,464	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	-	-	-	-	-	-	-	-	-	-
CI-2		X	2.5	5	20	566.3	232,775	-	-	108,572	32,829	46,490	22,680	15,196	4,324	2,682
CI-3		X	4	5	20	566.3	244,064	-	-	80,731	40,824	57,009	31,522	22,150	8,101	3,724

[a] Standard conditions = 25°C and 760 mm Hg.

[b] - Indicates no data directly available.

[c] Cyclone catch

[d] Backup filter.

DATA REPRODUCED IN TABLE 4-10

TABLE 3-13. SUMMARY OF TEST RESULTS FOR RUN S-3

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions: ft^3/min	Air flow rate[a] standard conditions: ℓ/min	Concentration of particulate matter measured by sampler ($\mu g/m^3$)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/impactor stages (µmA): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	-	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	107,508	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	-	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	78,710	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	248,194	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	-	-	-	-	-	-	-	-	-	-
CI-2		X	2.5	5	20	566.3	145,350	-	-	92,382	2,047	6,195	10,042	19,909	13,184	1,588
CI-3		X	4	5	20	566.3	359,993	-	-	244,245	4,606	13,519	26,069	43,701	25,698	2,153

[a] Standard conditions = 25°C and 760 mm Hg.

[b] - indicates no data directly available.

[c] Cyclone catch

[d] Backup filter.

DATA REPRODUCED IN TABLE 4-11

TABLE 3-14. SUMMARY OF TEST RESULTS FOR RUN S-4

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions ft^3/min	Air flow rate[a] standard conditions ℓ/min	Concentration of particulate matter measured by sampler ($\mu g/m^3$)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/impactor stages (μm): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	625	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	86,186	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	473	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	125,341	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	628,807	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	369	-	-	e	e	e	e	e	e	e
CI-2		X	2.5	5	20	566.3	237,711	-	-	184,372	13,308	22,856	8,595	5,648	1,765	1,164
CI-3		X	4	5	20	566.3	586,912	-	-	93,824	17,208	52,508	90,438	194,503	132,692	5,736

[a] Standard conditions = 25°C and 760 mm Hg.

[b] - indicates no data directly available.

[c] Cyclone catch

[d] Backup filter.

[e] Cannot be adequately determined given existing data.

DATA REPRODUCED IN TABLE 4-12

TABLE 3-15. SUMMARY OF TEST RESULTS FOR RUN S-5

Sampler ID No.	Type of sample: Upwind (background)	Type of sample: Downwind (source)	Sampling height (m)	Sampling duration (min)	Air flow rate[a] standard conditions: ft³/min	Air flow rate[a] standard conditions: ℓ/min	Concentration of particulate matter measured by sampler (µg/m³)[b]: Total particulate	Total suspended particulate	Inhalable particulate	Cyclone/impactor stages (µmA): > 11.36[c]	11.36-10.36	10.36-4.27	4.27-2.13	2.13-1.42	1.42-0.74	< 0.74[d]
TSP-1	X		2	60	45	1,274.2	-	273	-	-	-	-	-	-	-	-
TSP-2		X	2.5	5	45	1,274.2	-	8,681	-	-	-	-	-	-	-	-
IP-3	X		2	60	40	1,132.6	-	-	146	-	-	-	-	-	-	-
IP-4		X	2.5	5	40	1,132.6	-	-	5,545	-	-	-	-	-	-	-
IP-5		X	4	5	40	1,132.6	-	-	64,640	-	-	-	-	-	-	-
CI-1	X		2	60	20	566.3	423	-	-	260	5	16	22	32	44	42
CI-2		X	2.5	5	20	566.3	56,609	-	-	53,917	725	755	274	240	205	490
CI-3		X	4	5	20	566.3	59,439	-	-	46,172	4,363	3,206	1,343	853	39	3,461

[a] Standard conditions = 25°C and 760 mm Hg.

[b] - indicates no data directly available.

[c] Cyclone catch

[d] Backup filter.

DATA REPRODUCED IN TABLE 4-13

TABLE 3-5. EMISSION FACTORS BASED ON TOTAL MASS AND IMPACTOR SIZE DISTRIBUTION BAGHOUSE INLET AND OUTLET

Run No.	Total mass emission rate (lb/hr)[a]	Production rate (tons/day)	Total mass emission factor (lb/ton)	Ratio of total mass conc. to particle size train conc.	Emission factors 15 µm (lb/ton)[b]	10 µm (lb/ton)[b]	2.5 µm (lb/ton)[b]
Bag-I-1-1	1,842	276	160.2		82.0	56.1	32.7
Bag-I-1-2	1,271	276	110.5		64.8	46.9	9.2
Bag-I-1-3	1,816	276	157.9		87.6	61.7	13.2
Bag-I-1-4	1,227	276	106.7		64.8	43.1	1.9
Average	1,539	276	133.8	0.83	74.8	52.0	14.2
Bag-I-2-1	1,473	276	128.1		73.5	53.3	16.6
Bag-I-2-2(2)[c]	1,336	276	116.1		116.5	117.1	94.1
Bag-I-2-3(2)	1,548	276	134.6		82.3	57.4	10.0
Bag-I-2-4	1,129	276	98.1		56.7	40.8	11.0
Average	1,383	276	120.3	1.00	70.8	50.5	12.5
Bag-I-3-1	1,634	276	142.1		88.3	64.1	17.5
Bag-I-3-2	1,503	276	130.7		83.3	65.3	29.5
Bag-I-3-3	1,539	276	133.8		78.6	57.3	11.3
Bag-I-3-4	779	276	67.7		40.7	27.8	4.1
Average	1,364	276	118.9	0.88	72.7	53.6	15.6
Bag-I-4-1	1,369	276	119.1		67.0	44.6	9.8
Bag-I-4-2	881	276	76.6		44.9	32.8	8.6
Bag-I-4-3	1,392	276	121.1		70.6	48.6	9.1
Bag-I-4-4	1,341	276	116.6		74.6	53.9	7.9
Average	1,246	276	108.4	1.01	64.3	45.0	8.9
Total average	1,383	276	120.4	0.92	70.7	50.3	12.8

(continued)

DATA REPRODUCED IN TABLE 4-18

TABLE 3-5. (continued)

Run No.	Total mass emission rate (lb/hr)[a]	Production rate (tons/day)	Total mass emission factor (lb/ton)	Ratio of total mass conc. to particle size train conc.	Emission factors 15 µm (lb/ton)[b]	10 µm (lb/ton)[b]	2.5 µm (lb/ton)[b]
Bag-0-1-1[c]	0.45	276	0.04		0.08	0.07	0.003
Bag-0-1-2[c]	2.0	276	0.18		0.15	0.13	0.05
Bag-0-1-3(2)[c]	1.25	276	0.11		0.06	0.05	0.01
Bag-0-1-4[c]	2.30	276	0.20		0.18	0.15	0.06
Average	1.50	276	0.13	0.30	0.09	0.08	0.03
Bag-0-2-1	0.85	276	0.08		0.06	0.05	0.02
Bag-0-2-2	0.75	276	0.07		0.06	0.05	0.02
Bag-0-2-3	1.05	276	0.09		0.02	0.01	0.006
Bag-0-2-4	1.50	276	0.13		0.11	0.09	0.04
Average	1.05	276	0.09	0.87	0.06	0.05	0.02
Bag-0-3-1	1.05	276	0.09		0.09	0.07	0.03
Bag-0-3-2	1.65	276	0.15		0.14	0.14	0.05
Bag-0-3-3	1.05	276	0.09		0.01	0.01	0.006
Bag-0-3-4	1.00	276	0.09		0.06	0.06	0.03
Average	1.20	276	0.10	0.58	0.08	0.07	0.03
Bag-0-4-1	0.60	276	0.05		0.04	0.04	0.02
Bag-0-4-2	1.55	276	0.14		0.13	0.10	0.04
Bag-0-4-3	0.75	276	0.07		0.06	0.05	0.03
Bag-0-4-4	1.60	276	0.14		0.11	0.09	0.03
Average	1.15	276	0.10	0.97	0.09	0.07	0.03
Total average	1.25	276	0.11	0.65	0.08	0.06	0.03

[a] lb/hr = emission rate of entire baghouse, pounds per hour.

[b] lb/ton = pounds per ton of product.

[c] Not used in calculations due to suspect loading of the Brink Stages.

LR489E(P)

DATA REPRODUCED IN TABLE 4-19

TABLE 3-7. EMISSION FACTORS BASED ON TOTAL MASS AND IMPACTOR DISTRIBUTION ELECTROSTATIC PRECIPITATOR INLET AND OUTLET

Run No.	Total mass emission rate (lb/hr)[a]	Production rate (tons/day)	Total mass emission factor (lb/ton)[b]	Ratio of total mass conc. to particle size train conc.	Emission factors for: 15 µm (lb/ton)[b]	10 µm (lb/ton)[b]	2.5 µm (lb/ton)[b]
ESP-1-1-1	2,687.0	300	215.0		82.7	32.1	2.7
ESP-1-1-2	3,677.5	300	294.2		110.4	41.5	3.3
ESP-1-1-3	3,962.7	300	317.0		121.1	46.4	4.0
ESP-1-1-4	7,391.1	300	591.4		222.0	80.1	4.5
Average	4,429.7	300	354.4	1.12	134.0	50.0	3.6
ESP-1-2-1	3,853.3	300	308.3		144.5	73.2	2.9
ESP-1-2-2	4,491.3	300	359.3		359.3	59.7	4.8
ESP-1-2-3	5,875.9	300	470.1		181.7	70.0	5.1
ESP-1-2-4	4,697.3	300	375.8		162.6	73.3	3.0
Average	4,729.4	300	378.4	1.21	212.0	69.1	4.0
ESP-1-3-1	3,824.5	300	306.0		119.4	45.9	2.4
ESP-1-3-2	5,163.9	300	413.1		165.1	68.0	3.1
ESP-1-3-3	5,880.3	300	470.4		181.3	68.5	2.4
ESP-1-3-4	4,904.5	300	392.4		150.6	56.3	2.5
Average	4,943.3	300	395.5	1.28	154.1	59.7	2.6
ESP-1-4-1	4,670.0	300	373.6		147.4	58.6	3.7
ESP-1-4-2	4,688.6	300	375.1		134.2	49.0	1.9
ESP-1-4-3	3,711.7	300	296.9		117.2	46.5	1.8
ESP-1-4-4	4,903.4	300	392.3		153.2	61.6	4.0
Average	4,493.4	300	359.5	1.33	138.0	53.9	2.8
Total average	4,649.0	300	371.9	1.24	159.5	58.2	3.3

(continued)

DATA REPRODUCED IN TABLE 4-20

TABLE 3-7. (continued)

Run No.	Total mass emission rate (lb/hr)[a]	Production rate (tons/day)	Total mass emission factor (lb/ton)[b]	Ratio of total mass conc. to particle size train conc.	Emission factors for: 15 µm (lb/ton)[b]	10 µm (lb/ton)[b]	2.5 µm (lb/ton)[b]
ESP-0-1-1(2)	58.6	300	4.7		2.1	1.5	0.4
ESP-0-1-2(2)	53.4	300	4.3		3.8	2.5	0.8
ESP-0-1-3	161.2	300	12.9		8.0	6.3	1.5
ESP-0-1-4	132.9	300	10.6		9.0	6.7	1.9
Average	101.5	300	8.1	1.17	5.7	4.3	1.1
ESP-0-2-1	73.1	300	5.9		3.8	2.1	0.6
ESP-0-2-2	87.2	300	7.0		4.0	3.3	0.7
ESP-0-2-3	87.2	300	10.8		3.8	3.6	1.0
ESP-0-2-4	135.3	300	18.2		11.4	9.6	2.0
Average	27.0	300	10.5	1.14	5.8	4.7	1.1
ESP-0-3-1	110.2	300	8.8		7.0	4.7	1.7
ESP-0-3-2	90.0	300	7.2		6.2	4.3	1.4
ESP-0-3-3	120.5	300	9.7		4.6	4.2	1.2
ESP-0-3-4	131.2	300	10.5		6.9	6.4	2.2
Average	113.0	300	9.1	1.08	6.2	4.9	1.6
ESP-0-4-1	125.6	300	10.0		5.8	4.5	1.0
ESP-0-4-2	143.0	300	11.5		9.1	7.8	2.1
ESP-0-4-3	117.6	300	9.4		2.5	2.4	0.7
ESP-0-4-4	86.8	300	6.9		3.7	3.7	1.0
Average	118.3	300	9.5	1.15	5.3	4.6	1.2
Total average	115.9	300	9.3	1.19	5.8	4.6	1.3

[a] lb/hr = emission rate of all ESPs, pounds per hour.

[b] lb/ton = pounds per ton of product.

DATA REPRODUCED IN TABLE 4-21

TABLE 3-18. EMISSION FACTOR SUMMARY

Run No.	Type of truck	Type of material	Silt content (%)	Average air velocity through tunnel (ft/sec)	Calculated emission factor: Total particulate[a] (lb/ton)	Calculated emission factor: Inhalable particulate[b] (lb/ton)	Calculated emission factor: Fine particulate[c] (lb/ton)
S-1	Open	Limestone	40.1	580.4	1.676	0.896	0.166
S-2	Enclosed	Limestone	40.1	580.4	0.714	0.636	0.084
S-3	Enclosed	Limestone	40.1	608.3	0.816	0.508	0.088
S-4	Open	Limestone	40.1	608.3	1.332	1.144	0.352
S-5	Enclosed	Lime	29.6	400.0	0.302	0.124	0.016

Note: Overall emission factor = f(% silt, velocity, type of truck loaded).

[a] Particles < ~ 300 μmA

[b] Particles < 15 μmA

[c] Particles < 2.5 μmA

DATA REPRODUCED IN TABLE 4-22 AND TABLE 4-29

TABLE 3-19. AVERAGE EMISSION FACTORS FOR THE LOADING OF LIMESTONE

Type of loading operation	Average emission factor		
	Total particulate[a] (kg/Mg)[d]	Inhalable particulate[b] (kg/Mg)[d]	Fine particulate[c] (kg/Mg)[d]
Loading of limestone into open-bed trucks	0.75	0.51	0.13
Loading of limestone into tanker-type trucks	0.38	0.29	0.04

[a] Particles < ~ 300 μm.

[b] Particles < 15 μm.

[c] Particles < 2.5 μm.

[d] 1 kg = 10^3 g = 2.2 lb_m

1 Mg = 10^6 g = 1.1 short tons

1 kg/Mg = 2 lb/short ton

DATA REPRODUCED IN TABLE 4-29

TABLE 3-10. SUMMARY OF EMISSION FACTORS

	Test No.	Emission factors (lb/ton)[a] Total	15 μm	10 μm	2.5 μm
Baghouse Inlet	1	133.8	74.8	52.0	14.2
	2	120.3	70.8	50.5	12.5
	3	118.9	72.7	53.6	15.6
	4	108.4	64.3	45.0	8.9
	Average	120.4	70.7	50.3	12.8
Outlet	1	0.13	0.09	0.08	0.03
	2	0.09	0.06	0.05	0.02
	3	0.10	0.08	0.07	0.03
	4	0.10	0.09	0.07	0.03
	Average	0.11	0.08	0.06	0.03
Electrostatic Precipitator Inlet	1	354.4	134.0	50.0	3.6
	2	378.4	212.0	69.1	4.0
	3	395.5	154.1	59.7	2.6
	4	359.5	138.0	53.9	2.8
	Average	371.9	159.5	58.2	3.3
Outlet	1	8.1	5.7	4.3	1.1
	2	10.5	5.8	4.7	1.1
	3	9.1	6.2	4.9	1.6
	4	9.5	5.3	4.6	1.2
	Average	9.3	5.8	4.6	1.3
Dust Collector	1	1.8	0.17	0.15	0.06
	2	1.7	0.16	0.16	0.07
	3	3.0	0.32	0.27	0.10
	4	2.3	0.21	0.19	0.08
	Average	2.2	0.22	0.19	0.08

[a] lb/ton = pounds per ton of product

DATA USED IN CALCULATIONS SHOWN IN APPENDIX C

APPENDIX C

TOTAL PARTICULATE EMISSION FACTOR CALCULATIONS

TITLE Emission Factor Calculations for Lime Plants

PROJECT NO. 4892-L74 DRAWN JSK APPR. ________ DATE 9/20-9/30/83

- Reference 6: Warner Co., Bellefonte, PA

  Incompatable test method - delete data

- Reference 7: Marblehead Lime, Chicago, IL

  No operating hours specified - cannot calc. emission factor!

- Reference 8: Paul Lime Co., Douglas, AZ (Rating = C)

  Rotary kiln w/ gravel bed filter (No. 4)

  Two tests using EPA Method 5 (including impinger catch)

  Calc. Emission Factors w/o impinger catch:

  - For Test No. 4 - from p. 5 of test report

$$\frac{0.2830 \text{ gm. collected}}{15 \text{ lbs. part/hr.}} = \frac{0.1567 \text{ gm collected}}{X \text{ lbs. part./hr.}}$$

$$X = 8.3 \text{ lbs. part/hr.}$$

$$8.3 \frac{\text{lbs. part}}{\text{hr.}} \times \frac{1 \text{ hr.}}{15 \text{ short ton feed}} \times 1.102 \frac{\text{short ton}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} = 0.28 \frac{\text{kg}}{\text{Mg}}$$

$$0.28 \frac{\text{kg part.}}{\text{Mg feed}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 0.56 \frac{\text{kg part.}}{\text{Mg lime}}$$

  - For Test No. 5 - from p. 6 of test report

$$\frac{0.1426 \text{ gm collected}}{15 \text{ lbs part/hr.}} = \frac{0.0798 \text{ gm collected}}{X \text{ lbs part/hr}}$$

$$X = 8.4 \text{ lbs part/hr.}$$

$$8.4 \frac{\text{lbs. part.}}{\text{hr.}} \times \frac{1 \text{ hr.}}{15 \text{ short tons feed}} \times 1.102 \frac{\text{short ton}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} = 0.28 \frac{\text{kg}}{\text{Mg}}$$

$$0.28 \frac{\text{kg part.}}{\text{Mg feed}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 0.56 \frac{\text{kg part.}}{\text{Mg lime}}$$

$$\overline{EF} = \frac{0.56 + 0.56}{2 \text{ tests}} = 0.56 \text{ kg/Mg}$$

- Reference 9 – Basic Magnesia, Inc., Port St. Joe, FL

  No process data – cannot calc. emission factors

- Reference 10 – Paul Lime Plant, Douglas, AZ (Rating = C)

  Gas-fired rotary kiln w/ gravel bed filter (No. 5)

  Three Method 5 tests @ outlet (includes impinger catch)

  Calc. Emission Factors w/o impinger catch:

  – For Test No. 1 – from p. 6 of test report

$$\frac{0.0762 \text{ gm. collected}}{13.8 \text{ lbs part/hr.}} = \frac{0.0691 \text{ gm. collected}}{X \text{ lbs part/hr.}}$$

$$X = 12.5 \text{ lbs. part/hr.}$$

From p. 1 of report – 25.2 tons limestone/hr. to kiln for all test periods

$$12.5 \frac{\text{lbs. part}}{\text{hr.}} \times \frac{1 \text{ hr.}}{25.2 \text{ short tons feed}} \times 1.102 \frac{\text{short tons}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} = 0.248 \frac{\text{kg}}{\text{Mg}}$$

$$0.248 \frac{\text{kg part}}{\text{Mg feed}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 0.496 \frac{\text{kg part}}{\text{Mg lime}}$$

— For Test No. 2 - from p. 8 of test report

$$\frac{0.0564 \text{ gm. collected}}{9.9 \text{ lbs part/hr.}} = \frac{0.0546 \text{ gm. collected}}{X \text{ lbs part./hr.}}$$

$$X = 9.6 \text{ lbs. part/hr.}$$

$$9.6 \frac{\text{lbs part.}}{\text{hr.}} \times \frac{1 \text{ hr.}}{25.2 \text{ short tons feed}} \times 1.102 \frac{\text{short tons}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} = 0.19 \frac{\text{kg}}{\text{Mg}}$$

$$0.19 \frac{\text{kg part}}{\text{Mg feed}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 0.38 \frac{\text{kg part.}}{\text{Mg. lime}}$$

— For Test No. 3 - from p. 10 of test report

$$\frac{0.0599 \text{ gm collected}}{10.9 \text{ lbs part/hr.}} = \frac{0.0594 \text{ gm collected}}{X \text{ lbs. part./hr.}}$$

$$X = 10.8 \text{ lbs. part/hr}$$

$$10.8 \frac{\text{lbs. part.}}{\text{hr.}} \times \frac{1 \text{ hr.}}{25.2 \text{ short tons feed}} \times 1.102 \frac{\text{short ton}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} = 0.214 \frac{\text{kg}}{\text{Mg}}$$

$$0.214 \frac{\text{kg. part.}}{\text{Mg feed}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 0.428 \frac{\text{kg part}}{\text{Mg lime}}$$

$$\overline{EF} = \frac{0.496 + 0.38 + 0.428}{3 \text{ tests}} = 0.43 \text{ kg part/Mg lime}$$

④

- Reference 11 – Allied Products Co., Alabaster, AL

  Chapter IV on sampling procedures missing – delete data

- Reference 12 – Dow Chemical Co., Freeport, TX (74-LIM-6)

  (3) Natural Gas-Fired Rotary Kilns w/ two ESP in parallel

  (3) Method 5 tests on two ESP stacks

  Two kilns in operation during testing (dolomitic lime)

  From Table 2.1, page 4 of test report: Rating = B
  (Average EFs for North & South stack for EF (from kilns)

Table 2.1 Particulate Data Summary (English)

RUN NUMBER	1		2		3		Averages	
DATE / STACK DESIGNATION	April 30, 1974 NORTH	SOUTH	May 2, 1974 NORTH	SOUTH	May 3, 1974 NORTH	SOUTH	NORTH	SOUTH
Volume of Gas Sampled, DSCF (1)	43.29	99.62	130.23	130.66	133.72	136.16	102.41	122.40
Percent Moisture By Volume	10.5	17.1	17.6	17.9	10.2	18.6	16.1	17.9
Average Stack Temperature, °F	373	440	354	412	366	406	363	422
Stack Volumetric Flow Rate, DSCFM	49,144	47,836	45,911	42,965	46,310	45,693	47,124	45,498
Stack Volumetric Flow Rate, ACFM	93,550	97,820	85,523	85,190	87,954	90,540	89,000	91,520
Percent Isokinetic	120	110	105	110	108	110	111	113
Process Weight Rate, Ton/hr (2)	20.3	20.3	20.0	20.0	20.3	20.3	20.2	20.2
PARTICULATES - PROBE AND FILTER								
Mg	46.7	30.5	20.6	21.0	61.2	40.5	42.8	37.0
Gr/DSCF (3)	0.0065	0.0053	0.0036	0.0025	0.0050	0.0056	0.0037	0.0047
Gr/ACF	0.0037	0.0029	0.0019	0.0013	0.0028	0.0028	0.0046	0.0023
Lb/Hr	7.00	2.51	1.42	0.95	2.35	2.20	3.59	1.89
Lb/Ton Feed	0.344	0.124	0.071	0.048	0.116	0.108	0.177	0.093
PARTICULATES, TOTAL								
Mg	88.2	63.9	49.4	128.4	71.2	106.7	64.3	99.0
Gr/DSCF	0.0238	0.0230	0.0058	0.0047	0.0082	0.012	0.0146	0.0122
Gr/ACF	0.0062	0.0047	0.0038	0.0024	0.0043	0.006	0.0077	0.0060
Lb/Hr	12.42	4.85	2.28	5.45	3.25	4.74	4.85	4.76
Lb/Ton Feed	0.62	0.29	0.114	0.272	0.163	0.233	0.298	0.236
Percent Impinger Catch	46.8	30.2	38.1	82.7	28.1	63.6	36.9	58.2

Total feed = 40.6 TPY for both kilns

arth. mean = average emissions from each kiln

(1) Dry standard cubic feet at 70°F and 29.92 inches Hg.
(2) These values are averages for the kilns (see Table 3.1) i.e. total feed rate for run #1 was 40.6 ton per hour.
(3) Grains per DSCF.

– Test No. 1: 4/30/74 (average of North & South stacks)

$$\frac{(0.344 + 0.124)}{2}\ \frac{\text{lbs part}}{\text{ton feed}} \times 1.102\ \frac{\text{short ton}}{\text{Mg}} \times 0.454\ \frac{\text{kg}}{\text{lb}} \times 2\ \frac{\text{Mg feed}}{\text{Mg lime}} = 0.234\ \frac{\text{kg part}}{\text{Mg lime}}$$

– Test No. 2: 5/2/74 (average of North & South stacks)

$$\frac{(0.071 + 0.048)}{2}\ \frac{\text{lbs part}}{\text{ton feed}} \times 1.102\ \frac{\text{short ton}}{\text{Mg}} \times 0.454\ \frac{\text{kg}}{\text{lb}} \times 2\ \frac{\text{Mg feed}}{\text{Mg lime}} = 0.0595\ \frac{\text{kg part}}{\text{Mg lime}}$$

– Test No. 3: 5/3/75 (average of North & South stacks)

$$\frac{(0.116+0.108)}{2} \frac{\text{lbs. part}}{\text{ton feed}} \times 1.102 \frac{\text{short ton}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 0.112 \frac{\text{kg part}}{\text{Mg lime}}$$

$$\therefore \overline{EF} = \frac{0.234 + 0.0595 + 0.112}{3 \text{ tests}} = 0.135 \frac{\text{kg part.}}{\text{Mg lime}} \text{ for each kiln}$$

- Reference 13 – J.E. Baker Co., Millersville, OH (Rating = C)

Two Sources: Fuller Cooler – Uncontrolled (grate-type)
No. 1 Kiln w/ venturi scrubber – coal-fired rotary kiln producing dolomitic lime

Fuller Cooler on No. 2 Kiln producing dead-burned dolomite

(3) Method 5 tests for each source – emissions to atmos (either cooler stack or scrubber stack)

From page 7 of test report: cooler stack tests 1-3

Plant J.E. Baker Company, Millersville, Ohio   Stack Fuller Cooler Stack. - Kiln No. 2

Material Sampled	Test Number	1974 Date	Sampling Period	Stack Temp °F	Stack Flowrate SCFM Dry	Concentration gr/SCFD	Emission Rate lbs/hr	Opacity %	Process Weight Rate tons/hr
Filterable Particulate	1	5/21	13:00-14:00	116	14,800	0.086	10.9	0	9.8
Filterable Particulate	2	5/21	15:20-16:20	115	14,800	0.076	9.7	0	9.8
Filterable Particulate	3	5/21	16:42-17:42	115	14,800	0.127	16.1	0	9.8
Average				115	14,800	0.096	12.2	0	9.8 ← Product Rate per Table on p. 6
~~Total Particulate~~	~~1~~	~~5/21~~	~~13:00-14:00~~	~~116~~	~~14,800~~	~~0.088~~	~~11.1~~	~~0~~	~~9.8~~
~~Total Particulate~~	~~2~~	~~5/21~~	~~15:20-16:20~~	~~115~~	~~14,800~~	~~0.080~~	~~10.1~~	~~0~~	~~9.8~~
~~Total Particulate~~	~~3~~	~~5/21~~	~~16:42-17:42~~	~~115~~	~~14,800~~	~~0.130~~	~~16.5~~	~~0~~	~~9.8~~
~~Average~~				~~115~~	~~14,800~~	~~0.099~~	~~12.6~~	~~0~~	~~9.8~~

6

$$12.2\ \frac{\text{lbs. part}}{\text{hr.}} \times \frac{1\ \text{hr.}}{9.8\ \text{short tons lime}} \times 1.102\ \frac{\text{short tons}}{\text{Mg}} \times 0.454\ \frac{\text{kg}}{\text{lb}} = 0.623\ \frac{\text{kg part}}{\text{Mg lime}}$$

(average of test)

From page 8 of test report: scrubber stack test 1-3

Plant J.E. Baker Company, Millersville, Ohio   Stack Scrubber Exhaust Stack - Kiln No. 1

Material Sampled	Test Number	1974 Date	Sampling Period	Stack Temp °F	Stack Flowrate SCFM Dry	Concentration gr/SCFD	Emission Rate lbs/hr	Opacity %	Process Weight Rate tons/h
Filterable Particulate	1	5/22	13:16-15:31	151	58,700	0.101	51.0	10-15	35.39
Filterable Particulate	2	5/23	09:17-11:32	150	53,000	0.102	46.3	10-15	35.15
Filterable Particulate	3	5/23	12:16-14:31	150	56,300	0.127	61.5	10-15	35.15
Average				150	56,000	0.110	52.9	10-15	35.23
~~Total Particulate~~	~~1~~	~~5/22~~	~~13:16-15:31~~	~~151~~	~~58,700~~	~~0.118~~	~~59.3~~	~~10-15~~	~~35.39~~
~~Total Particulate~~	~~2~~	~~5/23~~	~~09:17-11:32~~	~~150~~	~~53,000~~	~~0.129~~	~~58.7~~	~~10-15~~	~~35.15~~
~~Total Particulate~~	~~3~~	~~5/23~~	~~12:16-14:31~~	~~150~~	~~56,300~~	~~0.138~~	~~66.7~~	~~10-15~~	~~35.15~~
~~Average~~				~~150~~	~~56,000~~	~~0.128~~	~~61.6~~	~~10-15~~	~~35.28~~

Emissions not in compliance with July 1, 1975 Ohio regs!

From page 6 of test report: production data for No. 1 Kiln

7

SUMMARY OF PROCESS DATA
J.E. BAKER COMPANY
Millersville, Ohio
May 21-23, 1974

Operation and Product	1974 Date	Source and Test Number	Time Period	Averages: Kiln Speed turns/hr	Coal Feedrate tons/hr	Stone Feedrate tons/hr	Flux Feedrate tons/hr	Product Rate tons/hr	Natural Gas Feedrate ft^3/hr
Kiln No. 2 Dead-burned Dolomite	5/21	Cooler Stack P-1,2,3	12:00-19:00	38.75	3.125	17.9	0.645	9.8	Not Used
Kiln No. 2 Dead-burned Dolomite	5/21	Cooler Stack P-1,2,3	24 Hours	38.7	3.10	19.44	0.68	9.72	Not Used
Kiln No. 1 Dolomitic Lime	5/22	Scrubber Stack P-1 SO_x-1,2,3	12:00-20:00	71.1	4.49	30.9	Not Used	13.3	Not Availabl
Kiln No. 1 Dolomitic Lime	5/22	Scrubber Stack P-1 SO_x-1,2,3	24 Hours	72	4.42	30.0	Not Used	12.93	6995
Kiln No. 1 Dolomitic Lime	5/23	Scrubber ~~Stack~~ P-2,3	08:00-15:00	73.1	4.25	30.9	Not Used	13.29	Not Availabl
Kiln No. 1 Dolomitic Lime	5/23	Scrubber Stack P-2,3	24 Hours	Not Available	4.30	30,62	Not Used	13.17	7050

For Test No. 1 – 5/22/74

$$51.0\ \frac{\text{lbs. part}}{\text{hr.}} \times \frac{1\ \text{hr.}}{13.3\ \text{short tons lime}} \times 1.102\ \frac{\text{short tons}}{\text{Mg}} \times 0.454\ \frac{\text{kg}}{\text{lb}} = 1.92\ \frac{\text{kg part}}{\text{Mg lime}}$$

For Test No. 2 – 5/23/74

$$46.3\ \frac{\text{lbs. part}}{\text{hr.}} \times \frac{1\ \text{hr.}}{13.29\ \text{short tons lime}} \times 1.102\ \frac{\text{short tons}}{\text{Mg}} \times 0.454\ \frac{\text{kg}}{\text{lb}} = 1.74\ \frac{\text{kg part}}{\text{Mg lime}}$$

For Test No. 3 – 5/23/74

$$61.5\ \frac{\text{lbs part.}}{\text{hr.}} \times \frac{1\ \text{hr.}}{13.29\ \text{short tons lime}} \times 1.102\ \frac{\text{short tons}}{\text{Mg}} \times 0.454\ \frac{\text{kg}}{\text{lb}} = 2.32\ \frac{\text{kg part}}{\text{Mg lime}}$$

$$\overline{EF} = \frac{1.92 + 1.74 + 2.32}{3\ \text{tests}} = 1.99\ \text{kg part/Mg lime}$$

(8)

- Reference 14 (74-LIM-1) - Bethlehem Mines Corp., Annville, PA

Coal-fired rotary kiln w/ baghouse producing quicklime

(3) Method 5 tests @ baghouse outlet (2 stacks out of 4)

From Table 1, page 4 of test report: Rating = B

TABLE 1

SUMMARY OF PARTICULATE RESULTS

DATE		1-22-74	1-23-74	1-24-74	AVERAGE
RUN		LM-1	LM-2	LM-3	
"A" DUCT:	TOTAL TRAIN				
	gr/scf*	0.024	0.024	0.025	0.024
	lb/hr	2.77	2.25	3.39	2.80
	FRONT HALF**				
	gr/scf*	0.020	0.021	0.021	0.021
	lb/hr	2.32	1.98	2.78	2.36
	% of total	83.8	88.0	82.0	84.3
"B" DUCT:	TOTAL TRAIN				
	gr/scf*	0.036	0.041	0.051	0.042
	lb/hr	5.13	7.83	7.01	6.66
	FRONT HALF**				
	gr/scf*	0.032	0.036	0.048	0.039
	lb/hr	4.62	6.92	6.62	6.05
	% of total	90.1	88.4	94.4	90.8
SYSTEM:	TOTAL TRAIN				
	gr/scf*	0.0305	0.0354	0.0380	0.0346
	lb/hr	15.80	20.16	20.80	18.92
	FRONT HALF**				
	gr/scf*	0.0268	0.0310	0.0340	0.0306
	lb/hr	13.88	17.80	18.80	16.33
	% of total	87.8	88.3	90.4	89.0
~~TOTAL:~~	~~lb/ton of feed~~	~~0.263~~	~~0.336~~	~~0.347~~	~~0.315~~

* 70°F, 29.92" Hg, dry

** Probe & Filter

From Table 5, page 10 of test report:

(9)

From Table 5, page 10 of test report:

TABLE 5

Summary of Operating Variables

Date	1/22	1/23	1/24
Test No.	1	2	3
Stone feed rate (tons/hr)	60	60	60
Coal feed rate (tons/hr)	5.1-5.5	5.25	5.5
Water (gallons/min)	28-29	28	31
Pressure drop (inches of W.C.)	4.3-4.4	4.3-4.4	4.1-4.3
Kiln speed (RPH)	78	78	78
Feed end temp. (°F)	915-925	910-920	920-930
Product temp. (°F)	175-185	160-180	160-165
Baghouse inlet temp. (°F)	505-520	485-490	520-530

} Avg. feed rate = 60 TPH

Using average loading & feedrate:

$$16.83 \frac{\text{lbs part}}{\text{hr}} \times \frac{1 \text{ hr.}}{60 \text{ short tons feed}} \times 1.102 \frac{\text{short ton}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 0.2807 \frac{\text{kg part}}{\text{Mg lime}}$$

- Reference 15 (75-LIM-8) - Woodville Lime, Woodville, OH

  No process data - cannot calc. emission factors

- Reference 16 (74-LIM-3-A) - Woodville Lime, Woodville, OH

  Inaccurate process data - delete data (see Ref. 19)

- Reference 17 (74-LIM-7) - Marblehead Lime, Gary, IN (Rating = C)

  Coal-fired rotary kiln w/ baghouse

  (1) Method 5 test on each of six stacks @ b.house outlet

  From Table 2-2, page 2-3 of test report:

  (EF's calculated based on emissions from each stack)

10

TABLE 2-2

PARTICULATE SUMMARY
METRIC UNITS

Run Number / Date	1 (June 11, 1974)	2 (June 11, 1974)	3 (June 12, 1974)	4 (June 12, 1974)	5 (June 13, 1974)	6 (June 13, 1974)	Average
Volume of Gas Sampled-Nm^3	5.14	4.61	4.64	4.73	5.46	5.16	4.96
Percent Moisture by Volume	6.5	4.8	6.3	7.5	7.4	6.5	6.5
Average Stack Temperature-°C	143.9	128.3	140.0	131.7	133.3	133.9	135.2
Stack Volumetric Flow Rate-Nm^3/min	674	635	656	602	705	656	655
Stack Volumetric Flow Rate-m^3/min	1,049	935	1,006	917	1,077	993	996
Percent Isokinetic	98.5	93.7	91.4	101.6	100.0	101.6	97.8
Percent Stack Opacity	0.031	0.005	0.055	0.000	0.031	0.003	0.021
Feed Rate-M ton/hr (limestone only)	34.26	34.26	35.04	35.04	34.66	34.66	34.65
Particulates - Probe & Filter Catch							
mg.	262.4	223.1	104.6	118.1	156.2	137.0	166.9
mg/Nm^3	51.1	48.4	22.5	25.0	28.6	26.6	33.7
mg/m^3	32.8	32.8	14.7	16.4	18.7	17.6	22.2
kg/hr	2.07	1.84	0.89	0.90	1.21	1.05	1.33
kg/M ton	0.0604	0.0537	0.0254	0.0257	0.0349	0.0303	0.0384
Particulates - Total Catch							
mg.	424.5	426.0	340.0	275.0	320.4	377.0	360.5
mg/Nm^3	82.6	92.4	73.3	58.1	58.7	73.1	73.0
mg/m^3	53.1	62.7	47.7	38.1	38.4	48.2	48.1
kg/hr	3.34	3.52	2.88	2.10	2.48	2.87	2.87
kg/M ton	0.0975	0.1027	0.0822	0.0599	0.0715	0.0828	0.0828
Percent Impinger Catch	38.2	47.6	69.2	57.1	51.2	63.7	54.5

2-3

For total emissions from baghouse add EF's for Test 1-6:

$$\text{Total EF} = 0.0604 + 0.0537 + 0.0254 + 0.0257 + 0.0349 + 0.0303$$

$$= 0.230 \text{ kg part / Mg feed}$$

$$0.230 \frac{\text{kg part}}{\text{Mg feed}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 0.460 \frac{\text{kg part}}{\text{Mg lime}}$$

- Reference 19 (74-LIM-3B) – Woodville Lime, Woodville, OH

  Incorrect production rates included in report as noted by C.E. Riley on 9/30/74 in Appendix D with no indication of proper correction factor included in the report

  Data deleted!

11

Reference 20 (74-LIM-5) – U.S. Lime, City of Industry, CA

Atmospheric hydrator w/ med-energy scrubber (Ducon)

(3) Method 5 test at scrubber outlet (Rating = C)

From Table 2, page 5 of report:

Table 2 SUMMARY OF RESULTS
(Metric Units)

Run Number	1	2	3	Average
Date:	4/16/74	4/17/74	4/18/74	
Volume of Gas Sampled - Nm^3 (a)	2.100	2.281	2.278	2.220
Percent Moisture by Volume **	44.5	48.0	47.5	46.7
Average Stack Temperature - °C	78.9	81.1	80.6	80.2
Stack Volumetric Flow Rate-Nm^3/min (b)	138.8	135.2	135.8	136.6
Stack Volumetric Flow Rate-m^3/min (c)	303.0	315.8	313.9	310.9
Percent Isokinetic	101.3	115.7	106.7	107.9
Percent Opacity	0	0	0	0
Feed Rate - M.ton/hr	12.7	12.7	12.7	12.7
Particulate - probe, cyclone, and filter catch				
mg	104.2	140.8	191.3	145.4
mg/Nm^3	49.6	61.7	84.0	65.5*
mg/m^3	22.7	26.3	36.2	26.6*
kg/hr	0.40	0.48	0.66	~~[illegible]~~
kg/M ton	0.031	0.038	0.052	0.040
Particulates - total catch				
mg	129.6	181.3	211.0	174.0
mg/Nm^3	61.7	79.5	92.6	78.4
mg/m^3	28.2	33.9	39.9	34.2
kg/hr	0.49	0.61	0.73	0.61
kg/M ton	0.039	0.048	0.057	0.048
Percent Impinger Catch	19.6	22.3	9.34	17.1

Non-isokinetic sampling in 2 out of 3 runs

From Table 3, page 7 of test report:

TABLE 3 - SUMMARY OF ATMOSPHERIC HYDRATOR AND WATER SCRUBBER
OPERATING DATA DURING SAMPLING

Date	4/16/74	4/17/74	4/18/74
Test No.	1	2	3
Lime Feed Rate (tons/hr)	14	14	14
Water Feed Rate (tons/hr)	7	7	7
Hydrated Lime Production (tons/hr)	17-18	17-18	17-18
Scrubber Water (lbs/min)	160-166	165-168	165-169
Scrubber Temp. before airbleed (°F)	203-206	202-210	208-215
Scrubber Temp. after airbleed (°F)	184-192	188-192	188-192

} Avg. = 14 TPH

Using average results for all three tests:

$$0.040 \frac{\text{kg part.}}{\text{Mg feed}} \times \frac{14 \text{ TPH (feed)}}{17.5 \text{ TPH (lime)}} = 0.032 \frac{\text{kg part.}}{\text{Mg hyd. lime}}$$

- Reference 21 (75-STN-7) – Brenner Co., Lancaster, PA (Rating = B)

Test data for: Primary crusher – uncontrolled
Screen & hammermill – uncontrolled
Crusher, screen, & hammermill baghouse outlet
Final screen – uncontrolled & bhouse outlet

For crusher, screen & hammermill baghouse (outlet A): from Table I, page 6 of report

Test No. 1 = 0.0007 kg/Mg limestone feed
Test No. 2 = 0.0002 " " " "
Test No. 3 = 0.0007 " " " "

$$\overline{EF} = \frac{0.0007 + 0.0002 + 0.0007}{3 \text{ tests}} = 0.0005 \frac{\text{kg part.}}{\text{Mg stone}}$$

For final screen baghouse (outlet B): from Table I, page 7 of report:

Test No. 1 = 0.001 kg/Mg limestone feed
Test No. 2 = 0.000008 " " " "
Test No. 3 = 0.00008 " " " "

$$\overline{EF} = \frac{0.001 + 0.000008 + 0.00008}{3 \text{ tests}} = 0.0004 \frac{\text{kg part.}}{\text{Mg stone}}$$

For uncontrolled primary crusher (inlet C): from Table I, page 8 of report:

Delete!

Test No. 1 = 0.008 kg/Mg limestone feed
Test No. 2 = 0.009 " " " "

$$\overline{EF} = \frac{0.008 + 0.009}{2 \text{ tests}} = 0.009 \frac{\text{kg part.}}{\text{Mg stone}}$$

For uncontrolled primary screen & hammermill (inlet D):
from Table I, page 9 of report:

Delete! Test No. 1 = 0.0003 kg part/Mg limestone feed
Test No. 2 = 0.62 " " " " "

$$\overline{EF} = \frac{0.0003 + 0.62}{2 \text{ tests}} = 0.31 \ \frac{\text{kg part.}}{\text{Mg stone}}$$

For uncontrolled secondary screen (inlet E): erroneous data

Delete!

- Reference 22 (74-LIM-4) - U.S. Lime, Henderson, NV

No process data - cannot calc. emission factors

Reference 23 - J.E. Baker Co., Millersville, OH (same kiln as Ref. 13)

No. 1 Coal-fired rotary kiln w/ venturi scrubber (dolomitic lime)

(3) Tests @ inlet & outlet of scrubber

Inlet = impingers followed by filter (modified Method 5)
Outlet = Method 5 (standard)

From page 2 of test report:

The analytical results wereas follows: (from p. 13-15)

Location	Test #	lb./hr.	w/o Impinger
Inlet	1	3412.*	—
	2	5210.*	—
	3	3202.*	—
	Avg.	3941.*	—
Outlet	4	37.51	31.76
	5	37.74	33.70
	6	36.37	35.60
	Avg.	37.21	33.69

Emissions in compliance w/ Ohio regs!

{ Per pages 8-11 inlet testing conducted on 2/27/75
{ " " 12-15 outlet " " " 2/28/75

Per process operating log in appendix:

{ Stone feed = 28.52 ton/hr. on 2/27/75
{ Stone feed = 28.92 ton/hr. on 2/28/75

∴ For Scrubber Inlet - 2/27/75

$$3941 \frac{\text{lbs. part}}{\text{hr.}} \times \frac{1 \text{ hr.}}{28.52 \text{ short tons feed}} \times 1.102 \frac{\text{short ton}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 138.3 \frac{\text{kg}}{\text{Mg}}$$

For Scrubber Outlet - 2/28/75

$$33.69 \frac{\text{lbs part}}{\text{hr.}} \times \frac{1 \text{ hr.}}{28.92 \text{ short tons feed}} \times 1.102 \frac{\text{short ton}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 1.166 \frac{\text{kg}}{\text{Mg}}$$

{ Inlet Data Rating = C }
{ Outlet " " = B }

- Reference 24 - VA Lime Co., Ripplemead, VA (Rating = B)

Coal-fired rotary kiln - uncontrolled

(3) Method 5 tests @ stack

From Table 1, page 4 of test report: correct all calculations for impinger catch

(Runs 1 & 2 incomplete - use Runs 3-5 for calculations)

(15)

Table 1

SUMMARY OF PARTICULATE RESULTS

	4/30/75		5/01/75		5/02/75		5/03/75		5/03/75	
Run Number	1		2		3		4		5	
Vol. of gas sampled (DSCF-Nm³)[a]	11.80	.334	19.59	.555	26.01	.736	23.71	.671	26.72	.757
% Moisture by volume	6.60	6.60	2.73	2.73	3.75	3.75	4.74	4.74	4.76	4.76
Average stack temp. (°F-°C)	403	206	392	200	388	198	394	201	395	202
Stack Volumetric Flow Rate (DSCFM-Nm³/sec)[b]	45515.	21.5	6109[illegible]	28.8	59260	28.0	53432	25.2	55795	26.3
Stack Volumetric Flow Rate (ACFM-m³/sec)[c]	84753	40.0	10[illegible]751	50.9	105181	49.6	96796	45.7	101159	47.8
% Isokinetic	98.8	98.8	90.5	90.5	92.9	92.9	94.0	94.0	101.4	101.4
Duration of run-minutes	26.7	26.7	36	36	48	48	48	48	48	48
Limestone Feed Rate (Ton/hr-metric ton/hr)	23	20.9	28	25.4	29	26.3	27	24.5	29	26.3
Particulates-probe, cyclone and filter catch										
mg	8944.1	8944.1	11072.5	11072.5	19586.7	19556.7	13125.0	13125.0	15864.7	15864.7
(grain/DSCF-gm/Nm³)[d]	11.6765	26.72	8.[illegible]061	19.92	11.5965	26.54	8.5239	19.51	9.1422	20.92
(lb/hr-kg/hr)	4554.6	206[illegible].9	455[illegible].0	2067.5	5889.4	2671.4	3903.2	1770.5	4371.4	1982.8
Particulates-total catch										
mg					19727.1	19727.1	13180.5	13180.5	15938.2	15938.2
(grains/DSCF-gm/Nm³)					11.6797	26.73	8.5509	19.59	9.1845	21.02
(lb/hr-kg/hr)					5931.5	2690.5	3919.7	1777.9	4391.19	1992.0
Percent impinger catch					0.7	0.7	0.4	0.4	0.5	0.5
Emission Factor										
lb/Ton-kg/MTon (Product)	396	197.6	325.6	162.[illegible]	409.1	204.6	290.3	145.2	302.8	151.4
lb/Ton-kg/MTon (Feed)	198	98.8	163	81.4	205	102.3	145	72.6	151	75.7

a - Dry standard cubic feet @ 70°F, 29.92 in Hg - normal cubic meters at 21.1°C, 760 mm Hg

b - Dry standard cubic feet per minute - normal cubic meters per second

c - Actual cubic feet per min., stack conditions - actual cubic meters per second

d - Grains per dry standard cubic feet - mg per normal cubic meters

For Test No. 3 - 5/2/75

$$204.6 \frac{\text{kg part.}}{\text{Mg lime}} \times \underbrace{(1 - 0.007)}_{\text{(less impinger catch)}} = 203.2 \frac{\text{kg part.}}{\text{Mg lime}}$$

For Test No. 4 - 5/3/75

$$145.2 \frac{\text{kg part.}}{\text{Mg lime}} \times \underbrace{(1 - 0.004)}_{\text{(less impinger catch)}} = 144.6 \frac{\text{kg part.}}{\text{Mg lime}}$$

For Test No. 5 - 5/3/75

$$151.4 \frac{\text{kg part.}}{\text{Mg lime}} \times \underbrace{(1 - 0.005)}_{\text{(less impinger catch)}} = 150.6 \frac{\text{kg part.}}{\text{Mg lime}}$$

$$\overline{EF} = \frac{203.2 + 144.6 + 150.6}{3 \text{ tests}} = 166.1 \text{ kg part/Mg lime}$$

16

- Reference 25 - U.S. Lime, Nelson, AZ (Rating = C)

Coal-fired rotary kiln (w/preheater) w/ gravel bed filter

(3) Method 5 test @ outlet of gravel bed

From page 1 of test report:

RESULTS ARE ENCLOSED OF THE STACK EMISSIONS ANALYSIS PERFORMED AT THE U. S. LIME PLANT AT NELSON, ARIZONA ON MAY 6 AND 7, 1975.

PARTICULATE EMISSIONS

TEST NUMBER 1 .... 36 LBS PER HR. PARTICULATES
TEST NUMBER 2 .... 37 LBS PER HR. PARTICULATES
TEST NUMBER 3 .... 35 LBS PER HR. PARTICULATES

SULFUR REMOVAL

APPARENT SULFUR REMOVAL 93%

THE STATE OF ARIZONA EMISSIONS STANDARDS ALLOW A PARTICULATE EMISSIONS RATE OF 46 LBS/HR. FOR THE RAW STONE FEED RATE OF 61 TONS PER HOUR, AND REQUIRE A MINIMUM SULFUR REMOVAL OF 90%.

$$\text{Average Emission Rate} = \frac{36+37+35}{3 \text{ tests}} = 36 \text{ lbs./hr}$$

$$36\,\frac{\text{lbs. part.}}{\text{hr}} \times \frac{1 \text{ hr.}}{61 \text{ short tons feed}} \times 1.102\,\frac{\text{short tons}}{\text{Mg}} \times 0.454\,\frac{\text{kg}}{\text{lb}} \times 2\,\frac{\text{Mg feed}}{\text{Mg lime}} = 0.59\,\frac{\text{kg part.}}{\text{Mg lime}}$$

- Reference 26 - J.E. Baker Co., Millersville, OH (Rating = C)

[redacted]o. 2 Coal-fired rotary kiln w/ venturi scrubber (dolomitic lime)

[redacted]ethod 5 tests @ scrubber outlet

From [redacted] 1 of test report:

PRINCETON CHEMICAL RESEARCH, INC.

1.

Kiln not in compliance w/ Ohio Regs!

SUMMARY OF RESULTS

Test #	1	2	3	Avg.
Particulate, lb/hr				
Found	69.41	129.14	47.28	81.94
Allowable	34.46	34.46	34.46	34.46

From Operating Log on page 11: Avg. stone feed = 20.07 tons/hr.

$$\therefore\ 81.94\ \frac{\text{lbs. part}}{\text{hr.}} \times \frac{1\ \text{hr}}{20.07\ \text{short tons feed}} \times 1.102\ \frac{\text{short tons}}{\text{Mg}} \times 0.454\ \frac{\text{kg}}{\text{lb}} = 2.043\ \frac{\text{kg part.}}{\text{Mg feed}}$$

$$2.043\ \frac{\text{kg part}}{\text{Mg feed}} \times 2\ \frac{\text{Mg feed}}{\text{Mg lime}} = 4.086\ \frac{\text{kg part.}}{\text{Mg lime}}$$

- Reference 27 - Marblehead Lime, Bellefonte, PA (Rating = D)

(3) Rotary kilns w/ two baghouse collectors (coal-fired)

(1) Test on four of 12 identical sections

Test method unspecified - assumed as ASME PTC-27

From Section II of test report:

		Mass Rate of Emissions Pounds per Hour	Allowable Emiss Pounds per
7/17/75	Baghouse "A" Section 1	2.8	
	Baghouse "B" Section 1	2.5	
	Subtotal	5.3	
	Total Emission from both Baghouses (Subtotal x 6 identical compartments)	31.8	56.8
7/19/75	Baghouse "A" Section 4	2.0	
	Baghouse "B" Section 4	3.0	
	Subtotal	5.0	
	Total Emissions from both Baghouses (Subtotal x 6 identical compartments)	30.0	58.9

avg = 30.9

Average Emission Rate Both Baghouses 30.9 Pounds/Hour — from both baghouses

No raw data included in report!

From Section IV of test report:

IV. PRODUCTION SUMMARY:

7/17			PRODUCTION IN TONS PER HOUR Kiln #1	Kiln #2	Kiln #3
Baghouse A Section 1	11:00 AM		9.8	10.3	11.2
	12:00 PM		12.3	12.4	8.3
	1:00 PM		12.2	11.1	8.1
Baghouse B Section 1	4:00 PM		10.5	8.2	13.0
	5:00 PM		11.3	9.5	9.1
	6:00 PM		12.4	7.6	12.5
		Total	68.5	59.1	62.2
		Average	11.4	9.9	10.4

7/18

Baghouse B Section 4	10:00 AM	12.2	11.7	12.2
	11:00 AM	12.3	11.1	12.2
	12:00 PM	12.3	11.2	12.2
Baghouse A Section 4	3:00 PM	12.3	10.7	13.0
	4:00 PM	12.0	8.0	12.5
	5:00 PM	12.2	7.5	12.5
	Total	73.3	60.2	74.6
	Average	12.2	10.0	12.4

For 7/17 Tests:

Total Production = 11.4 + 9.9 + 10.4 = 31.7 tons/hr

$$31.8 \frac{\text{lbs prt}}{\text{hr}} \times \frac{1 \text{ hr}}{31.7 \text{ short tons lime}} \times 1.102 \frac{\text{short ton}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} = 0.502 \frac{\text{kg prt}}{\text{Mg lime}}$$

For 7/18 Tests:

Total Production = 12.2 + 10 + 12.4 = 34.6 tons/hr

$$30.0 \frac{\text{lbs prt}}{\text{hr}} \times \frac{1 \text{ hr}}{34.6 \text{ short tons lime}} \times 1.102 \frac{\text{short ton}}{\text{Mg}} \times 0.454 \frac{\text{kg}}{\text{lb}} = 0.434 \frac{\text{kg prt}}{\text{Mg lime}}$$

$$\overline{EF} = \frac{0.502 + 0.434}{2 \text{ tests}} = 0.468 \text{ kg prt/Mg lime}$$

- Reference 28 (76-LIM-9) – Martin-Marietta, Calera, AL
  - Coal-fired rotary kiln w/ baghouse
  - Atmospheric hydrator w/ Ducon dynamic wet scrubber

    (6) Method 5 tests @ bhouse outlet (2/stack)

    (3) Method 5 tests @ hydrator scrubber outlet

    For the rotary kiln: from Table 1, page 4 of test report

    (2 tests/stack for 3 stacks – combine 3 stacks for total EF from kiln)

19

	A1	B1	A2	C1	C2	B2	

Table 1. SUMMARY OF PARTICULATE EMISSIONS FROM THE BAGHOUSE (METRIC)

St. no.	1	2	1	3	3	2	
Run no.	1	2	2	1	2	2	
Run Number	1-1	2-2	1-2	3-1	3-2	2-3	Average[b]
Date	9-9-75	9-10-75	9-10-75	9-12-75	9-11-75	9-12-75	
Volume of Gas Sampled							
Nm³[a]	1.90	2.33	2.23	2.43	2.48	2.00	
Percent moisture by volume	4.45	11.87	11.60	14.71	11.22	9.25	
Average stack temp. - °C	131	142	129	146	137	112	
Stack volumetric flow rate							
Nm³/min	278	293	298	302	319	269	
Percent Isokinetic	96.3	113.2	111.2	117.9	115.6	108.5	
Run Time - Minutes	132	132	132	132	132	132	
Particulates - Front half							
mg	42.9	21.2	31.8	27.4	40.8	15.2	59.5
mg/Nm³	22.8	9.1	14.1	11.3	16.5	7.6	40.7
Kg/hr	0.377	0.160	0.249	0.204	0.311	0.123	0.692
Particulates - Total							
mg	74.3	39.7	54.2	68.6	72.4	33.3	171.3
mg/Nm³	39.1	17.[illegible]	24.3	29.2	29.2	16.7	77.3
Kg/hr	0.65[illegible]	[illegible]	[illegible]	[illegible]	0.592	[illegible]	1.357
Percent Impinger Catch	42.3	46.7	42.0	60.1	43.6	54.3	47.6
Process Emission Rate							
kg/Mg Feed	[illegible]	[illegible]	0.0137	[illegible]	0.0171	0.0090	0.0406

a) Normal cubic meters at [illegible]

b) The average is for all 3 stacks combined

4 out of 6 runs not isokinetic

∴ Rating = C

Based on process data in Table 10, average emission factor calculated from front half catch

$$\therefore\ 0.0406\ \frac{\text{kg part.}}{\text{Mg feed}} \times 2\ \frac{\text{Mg feed}}{\text{Mg lime}} = 0.0812\ \frac{\text{kg part.}}{\text{Mg feed}}$$

(total kiln EF) average emission factor

For the atmos. hydrator - from Table 8, page 22 of report

Table 8. SUMMARY OF PARTICULATE EMISSIONS FROM THE HYDRATOR (METRIC)

Run Number	1	2	3	Average
Date	9-12-75	9-17-75	9-17-75	
Volume of Gas Sampled - Nm³	1.07	1.54	1.44	1.35
Percent Moisture	79.09	75.71	79.04	77.95
Average Stack Temp. - °C	93.9	93.3	95.0	94.1
Stack Volumetric Flow Rate - Nm³/min	34.18	44.63	34.89	37.90
Percent Isokinetic	89.4	99.1	118.5	
Run Time - Minutes	128	128	128	128
Particulates - Front half				
mg	278.6	509.5	980.4	589.5
mg/Nm³	260.4	330.8	680.8	424.0
Kg/hr	0.534	0.886	1.425	0.948

Rating = B

20

From Table 11, page 30 of test report:

Table 11. MARTIN-MARIETTA HYDRATOR PROCESS DATA

Date (1975)	Lime Feedrate (TPH)[a]	Water to Scrubber (GPM)[b]	Water to Hydrator (GPM)[b]	Hydrator Temp. (°F)
12 Sept.	18	20	13.5	206
17 Sept.	17.2	19	15.2	195
17 Sept.	18	19	16.4	196

[a]Ton per hour

[b]Gallon per minute

Average Input = $\frac{18 + 17.2 + 18}{3 \text{ days}}$ = 17.7 short tons feed/hr.

$\therefore$ 0.948 $\frac{\text{kg part.}}{\text{hr}} \times \frac{1 \text{ hr}}{17.7 \text{ short tons feed}} \times 1.102 \frac{\text{short tons}}{\text{Mg}} = 0.0590 \frac{\text{kg part.}}{\text{Mg feed}}$

From page 31 of Reference 36 (EPA-600/2-77-023r): 0.757 Mg feed/Mg hyd. lime

$\therefore$ 0.0590 $\frac{\text{kg part.}}{\text{Mg feed}} \times 0.757 \frac{\text{Mg feed}}{\text{Mg hyd. lime}} = 0.0447 \frac{\text{kg part.}}{\text{Mg hyd. lime}}$

- Reference 29 (76-LIM-10): Allied Products, Montevallo, AL

  Coal/Nat. Gas-fired Rotary Kiln w/ Multiclone + Venturi Scrubber

  (3) Method 5 tests @ scrubber outlet

  From Table 1, page 5 of test report:

21

Table 1. SUMMARY OF PARTICULATE EMISSIONS (Metric)

Rating = B

Run Number	1	2	3	Average
Date	9-15-75	9-16-75	9-16-75	
Volume of Gas Sampled - Nm^3	1.73	1.73	1.66	1.71
Percent Moisture by Volume	19.86	18.77	20.91	19.85
Average Stack Temperature - °C	64	64	66	65
Stack Volumetric Flow Rate - Nm^3/min	2748	2747	2583	2693
Percent Isokinetic	100.5	100.5	102.6	
Run Time - Minutes	120	120	120	120
Particulates - Front Half				
mg	119.30	85.20	121.30	108.60
mg/Nm^3	68.8	49.1	72.9	63.6
Kg/hr	11.330	8.085	11.281	10.232
Particulates - Total				
mg	131.90	93.00	131.30	118.74
mg/Nm^3	76.0	53.6	78.9	69.5
Kg/hr	12.526	8.825	12.211	11.187
Percent Impinger Catch	9.5	8.4	7.6	8.5

From Table 13, page 34 of ~~test~~ report:

Table 13. SUMMARY OF LIME KILN OPERATING DATA TAKEN DURING SAMPLING

Test	Date (1975)	Limestone Feed Rate (TPH)	Fuel (Coal) Feed Rate (TPH)	Fuel (Gas) Feed Rate (1000 CFM)	Stack Temp. °F	Oxygen %
1	9/15	51.6	6.7	15	345	0.5
2	9/16	51.6	6.5	15	340	0.5
3	9/16	51.6	5.9	34	340	0.5

Avg. = 51.6 TPH

$$10.232 \frac{\text{kg part.}}{\text{hr}} \times \frac{1 \text{ hr}}{51.6 \text{ short tons feed}} \times 1.102 \frac{\text{short tons}}{\text{Mg}} \times 2 \frac{\text{Mg feed}}{\text{Mg lime}} = 0.437 \frac{\text{kg part.}}{\text{Mg lime}}$$

- Reference 30 – J.E. Baker Co., Millersville, OH

No. 2 Coal-fired rotary kiln w/ venturi scrubber (same as Ref. 26)

(3) Method 5 tests @ scrubber outlet

Emissions in compliance w/ Ohio Regs!

Not clear in report what factors were used to calculate emission rates!

Delete Data!

(22)

- Reference 31. (75-PRP-4) - Beker Indus., Conda, ID

Phosphate rock calciner & grinder - not applicable to lime industry

- Reference 32 - Standard Lime, Woodville, OH (Rating = B)

(2) Coal-fired rotary kilns w/ cyclone + baghouse producing:

No. 4 kiln producing dolomitic quicklime (multiclone + bhouse)
No. 6 " " dead burned dolomitic lime (low eff. cyclone + bhous)

(2) Method 5 tests on each kiln @ outlet of cyclone(s)

From Table 1, page 4 of test report:

Table 1. SUMMARY OF PARTICULATE EMISSIONS FROM KILNS 4 AND 6 (METRIC)

	Kiln 4[c]			Kiln 6[d]		
Run Number - Kiln Number	1-4	2-4	Average	1-6	2-6	Average
Date	12-9-75	12-9-75		12-10-75	12-10-75	
Volume of Gas Samples - Nm^3 [a]	1.262	1.269	1.265	0.976	[illegible]	.851
Percent Moisture by Volume	6.90	2.36	4.13	3.60	3.35	3.48
Average Stack Temperature - °C	199	196	197	274	279	277
Stack Volumetric Flow Rate - Nm^3/min	1666	1649	1658	1511	1113	1312
Percent Isokinetic	91.7	93.1	92.4	98.1	101.9	100.0
Run Time - minutes	60	60	60	72	72	72
Particulates - Front Half						
mg	17751	5626		11964	11278	
g/Nm^3	14.084	4.438	9.261	12.274	15.144	13.709
kg/hr	1407	439	923	1112	1011	1062
Particulates - Total						
mg	17760	5635		11995	11344	
g/Nm^3	14.091	4.447	9.269	12.306	15.233	13.770
kg/hr	1409	440	924	1115	1017	1066
Percent Impinger Catch	0.05	0.20	0.125	0.26	0.59	0.420
Limestone Feed Rate - metric ton/hr	50.4	54.1	52.3	27.2	27.2	27.2
Production Rate - metric ton/hr	21.8	23.4	22.6	10.4	10.4	10.4
Emission Factor (b) - kg/MTon (Feed)	27.9	8.1	18.0	41.0	37.4	39.2
kg/MTon (Product)	64.6	18.5	41.7	137.[illegible]	97.[illegible]	102.5

a) Normal cubic meters at 20°C
b) Front half data only
c) Emission data collected after multiclone and preheater
d) Emission data after low efficiency cyclone

Kiln No. 4 = 41.7 kg part/Mg lime produced (multiclone)
Kiln No. 6 = 102.5 " " " " (low-eff cyclone)

- Reference 34 (76-LIM-11) - J.E. Baker Co., Millersville, OH

  No particulate emissions data - SO_2 only

- Reference 35 (76-LIM-12) - Martin Marietta Chem., Woodville, OH

  No particulate emissions data - SO_2 only

- Reference 37 (NLA Exhibit 4) - 2/9/77

  Coal-fired rotary kiln w/ baghouse

  Compliance test for particulates & SO_2

  Total catch reported - could be corrected from raw wts

  No process data reported! Delete data!

- Reference 40 (NLA Exhibit 2) - 5/77 (Rating = B)

  No. 5 rotary kiln w/ baghouse - coal-fired

  (1) Method 5 test conducted on each of six baghouse stacks

  From page 2 of test report:

[illegible] PARTICULATE

STACK TEST

[illegible]

Run Number / Date	1 5-4-77	2 5-5-77	3 5-6-77	4 5-7-77	5 5-9-77	6 5-20-77	AVG	TOTAL
Volume Gas Sampled [illegible]	53.255	55.981	48.116	55.685	63.977	49.574	53.348	[illegible]
Moisture, Volume	11.4	15.5	12.3	15.1	9.9	11.8	12.67	
Average Stack Temp, °F	408.0	428.0	420.5	420.5	426.5	372.3	411.80	
[illegible]	11,862	11,707	10,812	11,218	13,782	10,705	11,681	70,086
[illegible]	21,829	23,378	20,302	22,560	25,309	18,052	22,038	[illegible]
Isokinetic	97.1	102.4	96.0	103.4	100.1	99.9	99.82	
Feed Rate T/hr (Limestone only)	49.9	[illegible]	43.5	44.0	42.1	41.1	42.85	[illegible]
Coal Feed T/hr	6.3	[illegible]	6.2	6.1	6.1	6.0	6.07	[illegible]
Total [illegible]	50.2	48.2	49.7	50.1	48.2	47.1	48.92	
Particulates - Probe & Filter Catch								
mg	56.9	93.9	178.7	114.1	78.7	106.7	103.5	621.0
gr/DSCF	0.0165	0.0281	0.0560	0.0316	0.0180	0.0332	0.0302	
lb/hr	1.65	2.65	5.09	3.15	2.13	3.04	2.95	17.71
lb/ton Feed	0.0376	0.0529	0.1170	0.0716	0.0506	0.0740	0.0589	[illegible]
Particulates - Total Catch								
mg	411.0	201.7	203.6	132.2	217.6	131.0	216.3	1297.5
gr/DSCF	0.1192	0.0560	0.0652	0.0366	0.0524	0.0409	0.0627	
lb/hr	11.96	5.69	5.93	3.64	6.21	3.75	6.20	37.18
lb/ton Feed	0.2724	0.1339	0.1363	0.0827	0.1079	0.0812	0.1440	
% Impinger Catch	86.2	53.4	14.2	13.5	65.7	18.9	42.0	[illegible]

Avg. = 42.85 tons limestone feed/hr.

Total = 17.71 lbs part/hr. for entire bhouse

$$17.71\ \frac{\text{lbs. part}}{\text{hr.}} \times \frac{1\ \text{hr}}{42.85\ \text{tons feed}} \times 0.454\ \frac{\text{kg}}{\text{lb}} \times 1.102\ \frac{\text{tons}}{\text{Mg}} = 0.2068\ \frac{\text{kg}}{\text{Mg feed}}$$

$$0.2068\ \frac{\text{kg part}}{\text{Mg feed}} \times 2\ \frac{\text{Mg feed}}{\text{Mg lime}} = 0.4136\ \frac{\text{kg part.}}{\text{Mg lime}}$$

- Reference 41 (NLA Exhibit 3) – 5/24–5/26/77 (Rating: B)

Same plant as Reference 40

No. 5 rotary kiln w/ baghouse – coal-fired

(3) Method 5 tests conducted on one of six baghouse stacks to evaluate performance of new bags

From page 6 of the test report:

Plant #3 PARTICULATE

STACK TEST

Run Number / Date	1 5-24-77	2 5-25-77	3 5-26-77	AVG	AVERAGE X 6 STACKS
olume Gas Sampled, SCFD	54.655	49.233	54.339	52.742	
Moisture, Volume	14.0	15.4	13.9	14.4	
verage Stack Temp. oF	410.5	428.0	426.5	421.7	
CFM D	11,564	10,074	11,327	10,988	65,930
CFM	21,853	19,807	21,893	21,184	127,106
Isokinetic	101.9	105.4	103.5	103.6	
eed Rate T/hr (Limestone only)	46.23	53.52	46.58	48.78	
oal Feed T/hr	6.04	6.06	6.04	6.05	
otal FWR	52.27	59.58	52.62	54.82	
articulates - Probe & Filter Catch					
g	137.6	132.0	174.3	148.0	887.8
r/DSCF	0.0388	0.0413	0.0495	0.0432	
/hr	3.88	3.67	4.89	4.15	24.88
/ton feed	0.0839	0.0686	0.1050	0.0858	0.515
articulates - Total Catch					
g	144.2	145.5	203.4	164.4	986.2
r/DSCF	0.0407	0.0456	0.0577	0.0480	
/hr	4.08	4.05	5.70	4.61	27.66
/ton feed	0.0883	0.0757	0.1224	0.0955	0.5728
Impinger Catch	4.90	9.38	14.21	9.50	

$$0.515\ \frac{\text{lbs. part}}{\text{ton feed}} \times 0.454\ \frac{\text{kg}}{\text{lb}} \times 1.102\ \frac{\text{short ton}}{\text{Mg}} \times 2\ \frac{\text{Mg feed}}{\text{Mg lime}} = 0.515\ \frac{\text{kg part.}}{\text{Mg lime}}$$

(total bhouse emission)

- Reference 42 (NLA Exhibit 1) - Marblehead Lime, Bellefonte, PA 8/77 (Rating: C)

(3) coal-fired rotary kilns w/ two parallel baghouses

(1) Method 5 test conducted on each of two baghouse sections for both collectors using original bags

(2) Method 5 tests conducted on one section of Baghouse A after installation of new bags.

From page 3 of test report:

Plant No. 1

PARTICULATE STACK TEST

	EXISTING BAGS				NEW BAGS	
Baghouse-Section	B-1	A-4	B-4	A-1	A-4	A-4
Run Number	1	2	3	4	5	6
Date	8-09-77	8-09-77	8-11-77	8-11-77	8-12-77	8-12-77
olume Gas Sampled SCFD	53.010	49.073	59.166	43.865	62.486	56.211
Moisture, Volume	5.0	5.1	4.5	5.1	4.2	4.5
verage Stack Temp. °F	324	351	356	327	340	343
CFM D	12,630	11,610	13,550	10,174	14,720	12,930
CFM	19,590	18,640	21,720	15,810	23,110	20,460
Isokinetic	102.5	103.3	106.6	105.4	103.8	106.2
eed Rate T/hr (Limestone only)	25.8	25.4	23.1	20.6	23.6	24.1
oal Feed T/r	4.1	4.0	3.7	3.3	3.8	3.8
otal PWR	29.9	29.4	26.8	23.9	27.4	27.9
ime Production	13.7	13.5	12.2	10.9	12.5	12.8
rticulates - Probe & Filter Catch						
:	176.1	319.4	283.7	126.0	126.6	148.4
/DSCF	0.051	0.100	0.074	0.044	0.031	0.041
/hr	5.62	10.16	8.88	3.98	4.02	4.65
/ton feed	0.87	1.60	1.54	0.77	0.68	0.77
rticulates - Total Catch						
:	256.5	360.8	321.2	182.3	151.9	174.2
/DSCF	0.075	0.113	0.084	0.064	0.037	0.048
/hr	8.19	11.47	10.06	5.75	4.82	5.46
/ton feed	1.27	1.81	1.74	1.12	0.82	0.91
Impinger Catch	31.4	11.4	11.7	30.8	16.6	14.8

Avg. 3 Kilns

B Bhouse

A Bhouse

15

- For A Baghouse: Existing Bags

$$\underbrace{\left(\frac{10.16+3.98}{2}\right)}_{\text{(average / section)}} \frac{\text{lbs part}}{\text{hr.}} \times 6 \text{ sections} \times 0.454 \frac{\text{kg}}{\text{lb}} = 19.3 \frac{\text{kg part}}{\text{hr}} \text{ (for A bhouse)}$$

– For B Baghouse: Existing Bags

$$\underbrace{\left(\frac{5.62 + 8.88}{2}\right)}_{\text{(average / section)}} \frac{\text{lbs part}}{\text{hr.}} \times 6 \text{ sections} \times 0.454 \frac{\text{kg}}{\text{lb}} = 19.8 \frac{\text{kg part}}{\text{hr.}}$$

(for B bhouse)

– Total for 3 Kilns: Existing Bags

$$19.3 \frac{\text{kg part}}{\text{hr.}} + 19.8 \frac{\text{kg part}}{\text{hr.}} = 39.1 \frac{\text{kg part}}{\text{hr.}}$$

– Total Production Rate for 3 Kilns: Existing Bags

$$\left(\frac{13.7 + 13.5 + 12.2 + 10.9}{4}\right) \frac{\text{tons lime}}{\text{hr}} \times 3 \text{ kilns} = 37.7 \frac{\text{tons}}{\text{hr.}}$$

$$37.7 \frac{\text{short tons lime}}{\text{hr.}} \times \frac{1 \text{ Mg}}{1.102 \text{ short ton}} = 34.2 \frac{\text{Mg lime}}{\text{hr.}}$$

– Average Emission Factor for 3 Kilns: Existing Bags

$$39.1 \frac{\text{kg part.}}{\text{hr.}} \times \frac{1 \text{ hr}}{34.2 \text{ Mg lime}} = 1.14 \frac{\text{kg part}}{\text{Mg lime}}$$

– For Both Baghouses w/ new bags:

$$\left(\frac{4.02 + 4.65}{2}\right) \frac{\text{lbs. part}}{\text{hr}} \times 6 \frac{\text{sections}}{\text{bhouse}} \times 2 \text{ bhouse} = 52.0 \frac{\text{lbs}}{\text{hr.}}$$

– Total Production Rate for 3 Kilns:

$$\left(\frac{12.5 + 12.8}{2}\right) \frac{\text{tons lime}}{\text{hr.}} \times 3 \text{ kilns} = 38.0 \frac{\text{short tons lime}}{\text{hr.}}$$

$$\therefore 52.0 \frac{\text{lbs. part}}{\text{hr.}} \times \frac{1 \text{ hr.}}{38.0 \text{ tons lime}} \times 0.454 \frac{\text{kg}}{\text{lb}} \times 1.102 \frac{\text{tons}}{\text{Mg}} = 0.685 \frac{\text{kg part}}{\text{Mg lime}}$$

– Average Emissions for Old & New Bags:

(27)

$$\left(\frac{1.14 + 0.685}{2}\right) \frac{\text{kg part.}}{\text{Mg lime}} = 0.913 \frac{\text{kg part.}}{\text{Mg lime prod.}}$$

- Reference 45 – Pfizer, Inc., Gibsonburg, OH (Rating: A)

Coal-fired rotary kiln w/ cyclone + baghouse
" " " " w/ ESP
(P.3) Pick-up points on belt transfer stations

Inlet & Outlet of dust collectors using IP protocol

From Table 3-10, page 82 of test report:

TABLE 3-10. SUMMARY OF EMISSION FACTORS

	Test No.	Emission factors (lb/ton)[a] Total	15 µm	10 µm	2.5 µm	Averages
Baghouse Inlet	1	133.8	74.8	52.0	14.2	T.P. = 60.2 kg/Mg
	2	120.3	70.8	50.5	12.5	
	3	118.9	72.7	53.6	15.6	
	4	108.4	64.3	45.0	8.9	
	Average	120.4	70.7	50.3	12.8	
Outlet	1	0.13	0.09	0.08	0.03	T.P. = 0.055 kg/Mg
	2	0.09	0.06	0.05	0.02	
	3	0.10	0.08	0.07	0.03	
	4	0.10	0.09	0.07	0.03	
	Average	0.11	0.08	0.06	0.03	
Electrostatic Precipitator Inlet	1	354.4	134.0	50.0	3.6	T.P. = 186.0 kg/Mg
	2	378.4	212.0	69.1	4.0	
	3	395.5	154.1	59.7	2.6	
	4	359.5	138.0	53.9	2.8	
	Average	371.9	159.5	58.2	3.3	
Outlet	1	8.1	5.7	4.3	1.1	T.P. = 4.7 kg/Mg
	2	10.5	5.8	4.7	1.1	
	3	9.1	6.2	4.9	1.6	
	4	9.6	5.3	4.8	1.2	
	Average	9.3	5.8	4.6	1.3	
Dust Collector	1	1.8	0.17	0.15	0.06	Delete Data
	2	1.7	0.16	0.16	0.07	
	3	3.0	0.32	0.27	0.10	
	4	2.3	0.21	0.19	0.08	
	Average	2.2	0.22	0.19	0.08	

[a] lb/ton = pounds per ton of product

APPENDIX D

COMPUTER PRINTOUTS OF SPLINE ANALYSIS FOR PARTICLE SIZE DISTRIBUTIONS

Analysis of Data

from

REFERENCE 24 (SECTION 4.0)

Feairheller, W.R. and T. L. Peltier, Air Pollution Emission Test, Virginia Lime Company, Ripplemead, VA, EPA Contract No. 68-02-1404, (EPA, Office of Air Quality Planning and Standards), Monsanto Research Corporation, Dayton, OH, April/May 1975.

From Table 1, page 4 of test report: Correct emission factors for impinger catch

Table 1

SUMMARY OF PARTICULATE RESULTS

	4/30/75		5/01/75		5/02/75		5/03/75		5/03/75	
Run Number	1		2		3		4		5	
Vol. of gas sampled (DSCF-Nm³)[a]	11.80	.334	19.59	.555	26.01	.736	23.71	.671	26.72	.757
% Moisture by volume	6.60	6.60	2.71	2.71	1.75	1.75	4.74	4.74	4.76	4.76
Average stack temp. (°F-°C)	403	206	392	200	388	198	394	201	395	202
Stack Volumetric Flow Rate (DSCFM-Nm³/sec)[b]	45515	21.5	61090	28.8	59260	28.0	53432	25.2	55795	26.3
Stack Volumetric Flow Rate (ACFM-m³/sec)[c]	84753	40.0	107751	50.9	105183	49.6	96796	45.7	101159	47.8
% Isokinetic	98.9	98.8	90.5	90.5	92.9	92.9	94.0	94.0	101.4	101.4
Duration of run-minutes	26.7	26.7	36	36	48	48	48	48	48	48
Limestone Feed Rate (Ton/hr-metric ton/hr)	23	20.9	28	25.4	29	26.3	27	24.5	29	26.3
Particulates-probe, cyclone and filter catch										
mg	8944.1	8944.1	11072.5	11072.5	19586.7	19596.7	13125.0	13125.0	15864.7	15864.7
(grain/DSCF-gm/Nm³)[d]	11.6765	26.72	8.7061	19.92	11.5965	26.54	8.5239	19.51	9.1422	20.92
(lb/hr-kg/hr)	4554.6	2065.9	4558.0	2067.5	5909.4	2671.4	3903.2	1770.5	4371.4	1982.8
Particulates-total catch										
mg					19727.1	19727.1	13180.5	13180.5	15938.2	15938.2
(grains/DSCF-gm/Nm³)					11.6797	26.73	8.5599	19.59	9.1845	21.92
(lb/hr-kg/hr)					5931.5	2690.5	3919.7	1777.9	4391.19	1992.0
Percent impinger catch					0.7	0.7	0.4	0.4	0.5	0.5
Emission Factor										
lb/Ton-kg/mTon (Product)	396	197.6	325.6	162.8	409.1	204.6	290.3	145.2	302.8	151.4
lb/Ton-kg/mTon (Feed)	198	98.8	163	81.4	205	102.3	145	72.6	151	75.7

a - Dry standard cubic feet @ 70°F, 29.92 in Hg - normal cubic meters at 21.1°C, 760 mm Hg

b - Dry standard cubic feet per minute - normal cubic meters per second

c - Actual cubic feet per min., stack conditions - actual cubic meters per second

d - Grains per dry standard cubic feet - mg per normal cubic meters

Particle Size Run #3 - 5/2/75

Use T.P. Run #3 data above:

$$204.6 \frac{\text{kg part.}}{\text{Mg product}} \times \underset{\text{(impinger catch)}}{(1 - 0.007)} = 203.2 \text{ kg/Mg product}$$

Particle Size Run #4 - 5/3/75

Use averages of T.P. Runs # 4 & 5 data above:

T.P. Run #4 data:

$$145.2 \frac{\text{kg part}}{\text{Mg product}} \times \underset{\text{(impinger catch)}}{(1 - 0.004)} = 144.6 \text{ kg/Mg product}$$

T.P. Run #5 data:

$$151.4 \frac{\text{kg part.}}{\text{Mg product}} \times \underset{\text{(impinger catch)}}{(1 - 0.005)} = 150.6 \text{ kg/Mg product}$$

$$\text{Average} = \frac{144.6 + 150.6}{2} = 147.6 \text{ kg part./Mg product}$$

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: VA LIME TEST RUN 1 KILN OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 1 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
.34	1.72
.56	1.93
1.1	2.1
1.62	2.24
2.77	2.9
10	3.55
200	100

OUTPUT DATA: TP EMISSION FACTOR = 406.4 LB/T (203.2 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	1.95645	7.95099	3.9755
1	2.07096	8.41637	4.20819
1.25	2.12438	8.63348	4.31674
2.5	2.77395	11.2733	5.63667
5	3.24994	13.2078	6.60388
10	4.15642	16.8917	8.44585
15	7.95872	32.3442	16.1721
20	14.252	57.9203	28.9602

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: VA LIME TEST RUN 2 KILN OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 1 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
.18	1.32
.36	1.4
.75	1.55
1.13	1.85
1.96	2.06
10	2.92
200	100

OUTPUT DATA: TP EMISSION FACTOR = 295.2 LB/T (147.6 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	EMISSION FACTOR (KG/MT)
.625	1.51062	4.45936	2.22968
1	1.76458	5.20905	2.60452
1.25	1.89198	5.58512	2.79256
2.5	2.16433	6.38912	3.19456
5	2.5117	7.41452	3.70726
10	3.65955	10.803	5.40149
15	7.50218	22.1464	11.0732
20	13.8449	40.8701	20.435

END OF TEST SERIES

Analysis of Data

from

REFERENCE 29 (SECTION 4.0)

Peltier, T.A., et al., Air Pollution Emission Test, Allied Products Company, Montevallo, AL, EPA Contract No. 68-02-1404, Task 20, (EPA, Office of Air Quality Planning and Standards), Monsanto Research Corporation, Dayton, OH, September 1975.

TEST ID: ALLIED LIME KILN 3 TEST 1 VENTURI SCRUBBER INLET

INPUT DATA:

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
.61	1.13
.98	1.34
1.87	1.58
2.73	2.61
4.63	3.55
10	12.11
200	100

OUTPUT DATA:

CUT (umA)	CUM. % < CUT
.625	1.14108
1	1.34614
1.25	1.42895
2.5	2.35077
5	4.01065
10	12.1467
15	21.6317
20	30.8487

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: ALLIED LIME - KILN 3 TEST 2 VENTURI SCRUBBER INLET

INPUT DATA:

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
.7	.53
1.09	.73
2.05	.93
3	1.58
5.06	3.19
10	5.93
200	100

OUTPUT DATA:

CUT (umA)	CUM. % < CUT
.625	.478675
1	.692466
1.25	.774445
2.5	1.2185
5	3.12967
10	6.1223
15	11.3991
20	18.7188

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: ALLIED LIME KILN 3 TEST 3 VENTURI SCRUBBER INLET

INPUT DATA:

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
.64	1.27
1.02	1.39
1.94	1.54
2.83	1.72
4.79	2.99
10	6.09
200	100

OUTPUT DATA:

CUT (umA)	CUM. % < CUT
.625	1.26372
1.25	1.38295
2.5	1.42457
5	1.65772
10	3.11477
15	6.29556
20	11.773
	19.1933

END OF TEST SERIES

TEST ID: ALLIED LIME KILN 3 TEST 2 VENTURI SCRUBBER INLET

INPUT DATA:

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
.7	.53
1.09	.73
2.05	.93
3	1.58
5.06	3.19
10	5.93
200	100

OUTPUT DATA:

CUT (umA)	CUM. % < CUT
.625	.478675
1	.692466
1.25	.774445
2.5	1.2185
5	3.12967
10	6.1223
15	11.3991
20	18.7188

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: ALLIED LIME KILN 3 TEST 3 VENTURI SCRUBBER INLET

INPUT DATA:

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
.64	1.27
1.02	1.39
1.94	1.54
2.83	1.72
4.79	2.99
10	6.09
200	100

OUTPUT DATA:

CUT (umA)	CUM. % < CUT
.625	1.26372
1	1.38295
1.25	1.42457
2.5	1.65772
5	3.11477
10	6.29556
15	11.773
20	19.1933

END OF TEST SERIES

Analysis of Data

from

REFERENCE 32 (SECTION 4.0)

Feairheller, W.R., et al., Source Test of a Lime Plant, Standard Lime Company, Woodville, OH, EPA Contract No. 68-02-1404, Task 12, (EPA, Office of Air Quality Planning and Standards), Monsanto Research Corporation, Dayton, OH, December 1975.

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: STANDARD LIME KILN 4 MULTICLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 1 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
.16	.7
.32	3.31
.79	6.11
1.26	9.02
2.3	18.14
10	39.28
200	100

OUTPUT DATA: TP EMISSION FACTOR = 129.2 LB/T (64.6 KG/MT)

CUT (umA)	CUM. % < CUT	EMISSION FACTOR (LB/T)	(KG/MT)
.625	5.2304	6.75768	3.37884
1	7.32057	9.45817	4.72908
1.25	9.01202	11.6435	5.82176
2.5	19.2753	24.9037	12.4519
5	28.9508	37.4044	18.7022
10	39.4997	51.0336	25.5168
15	47.5517	61.4368	30.7184
20	54.3004	70.1562	35.0781

END OF TEST SERIES

SPLIN2 PROGRAM - 02/22/82 V1

TEST ID: STANDARD LIME KILN 6 CYCLONE OUTLET

INPUT DATA: PROCESS WEIGHT RATE = 0 TONS PROD./HR
TOTAL PARTICULATE EMISSION RATE = 0 LB/HR
PARTICLE DENSITY = 1 G/CC

MEASURED SIZE DISTRIBUTION

CUT(um)	CUM. % < CUT
.23	.71
.45	3.97
1.07	5.07
1.7	6.37
3.09	14.59
10	21.16
200	100

OUTPUT DATA: TP EMISSION FACTOR = 205 LB/T (102.5 KG/MT)

		EMISSION FACTOR	
CUT (umA)	CUM. % < CUT	(LB/T)	(KG/MT)
.625	4.53523	9.29722	4.64861
1	4.96077	10.1696	5.08479
1.25	5.28142	10.8269	5.41345
2.5	11.2281	23.0176	11.5088
5	17.8123	36.5151	18.2576
10	21.5906	44.2607	22.1304
15	27.2966	55.9581	27.9791
20	33.9056	69.5064	34.7532

END OF TEST SERIES

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/7-86-031		

4. TITLE AND SUBTITLE	5. REPORT DATE
Lime and Cement Industry Particulate Emissions: Source Category Report; Volume I. Lime Industry	September 1986
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
John S. Kinsey	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Midwest Research Institute 425 Volker Boulevard Kansas City, Missouri 64110	11. CONTRACT/GRANT NO. 68-02-3999, Task 3
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development **Air and Energy Engineering Research Laboratory** **Research Triangle Park, NC 27711**	Task Final; 6/84-7/86
	14. SPONSORING AGENCY CODE **EPA/600/13**

15. SUPPLEMENTARY NOTES AEERL project officer is Dale L. Harmon, Mail Drop 61, 919/541-2429; Volume II is for the cement industry.

16. ABSTRACT The report gives results of a study to develop particulate emission factors based on cutoff size for inhalable particles for the lime industry. After reviewing available information characterizing particulate emissions from lime plants, the data were summarized and rated in terms of reliability. Size specific emission factors were developed from these data for the major processes used in the manufacture of lime. A detailed process description was presented with emphasis on factors affecting the generation of emissions. A replacement for Section 8.15 (Lime Manufacturing) of EPA report AP-42, Compilation of Air Pollutant Emissions Factors, was prepared, containing the size specific emission factors developed during this program.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution Emission	Pollution Control	13B
Calcium Oxides	Stationary Sources	07B
Industrial Processes	Lime Manufacturing	13H
Particles	Emission Factors	14G
Dust	Inhalable Particulate	11G
Aerosols		07D

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	278
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)