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SCREENING STUDY FOR EMISSIONS CHARACTERIZATION FROM LIME MANUFACTURE

Prepared For
Environmental Protection Agency
Office of Air Programs
Industrial Studies Branch

by

Vulcan-Cincinnati, Inc.
Cincinnati, Ohio
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1.0 INTRODUCTION

The intent of this report is to assist the Federal Environmental Protection Agency in developing standards of performance for controlling emissions from lime manufacture. This report has been developed following a survey of lime manufacturing and emission control in the States of Ohio, Texas, Pennsylvania, Missouri and Alabama. In this survey, the state air control agencies were visited and data was collected on the individual lime plants. Several lime plants were also visited for the purpose of seeing not only different lime manufacturing processes, but also different emission control devices.

This report is divided into five major sections. In the first section, background information is provided for the lime industry, along with descriptions of the various processes associated with lime manufacture. Process fuels are also discussed in this section. In the second major section of this report, emission control technology for lime processes is discussed. This discussion includes both United States and foreign technology. The environmental effects of lime manufacturing emissions are dealt with in the third major section, with individual attention being given to air pollution, water pollution, solid waste pollution, and energy consideration. In the fourth section, the economic aspects of the various emission control devices are discussed. The final major section compares possible new source emission standards to existing rotary lime kiln emissions in the five states surveyed.

2.0 PROCESS DESCRIPTION

2.1 GENERAL

Lime is made by the calcining of raw material stone which is more than 50% calcium carbonate. The raw stone is subjected to temperatures of about 2000°F and the carbonate breaks down chemically to release carbon dioxide. The finished product, basically calcium oxide, CaO, is commonly called burnt lime or quench lime. A secondary component of many limestone deposits is dolomite, calcium magnesium carbonate. Quarry stone is usually identified in terms of its dolomite and calcite (pure calcium carbonate) content. High calcium limestone is a general term for stone that contains largely calcium carbonate, $CaCO_3$, and not much magnesium carbonate, $MgCO_3$ (only a maximum of 2-5%). Dolomitic limestone contains considerable $MgCO_3$ (up to 45.6%); however, the term is loosely used to describe any carbonate rock that contains more than 20% magnesium carbonate.

In 1973, lime manufacturer amounted to more than 21 million tons, being produced at 185 plants in 42 states. Leading states in the production of lime are: Ohio, Pennsylvania, Texas, Michigas, Missouri, New York, Illinois, and Alabama. The primary uses of lime are chemical, construction, refractory materials, and agriculture. Figure 2.1, page 5, illustrates the trends in the major uses of lime since 1945.

The term "lime" also has a broad connotation and is frequently employed in referring to limestone. According to precise definition, which is confirmed by Webster, 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 impurities. In hydrated lime, the oxide is converted into a hydroxide by slaking, an exothermic reaction in which the water combines chemically with the lime. The reversible reactions for both high calcium and dolomitic types are:[3]

CALCINATION[3]

$$\underset{\text{High-Calcium Limestone}}{CaCO_3} + \text{heat} \rightleftharpoons \underset{\text{High-Calcium Quicklime}}{CaO} + CO_2$$

$$\underset{\text{Dolomitic Limestone}}{CaCO_3 \cdot MgCO_3} + \text{heat} \rightleftharpoons \underset{\text{Dolomitic Quicklime}}{CaO \cdot MgO} + 2CO_2$$

HYDRATION[3]

$$\underset{\text{High-Calcium Quicklime}}{CaO} + H_2O \rightleftharpoons \underset{\text{High-Calcium Hydrate}}{Ca(OH)_2} + \text{heat}$$

$$\underset{\text{Dolomitic Quicklime}}{CaO \cdot MgO} + H_2O \rightleftharpoons \underset{\text{Dolomitic Hydrate}}{Ca(OH)_2 \cdot MgO} + \text{heat}$$

$$\underset{\text{Dolomitic Quicklime}}{CaO \cdot MgO} + 2H_2O \rightleftharpoons \underset{\text{Dolomitic Hydrate}}{Ca(OH)_2 \cdot Mg(OH)_2} + \text{heat}$$

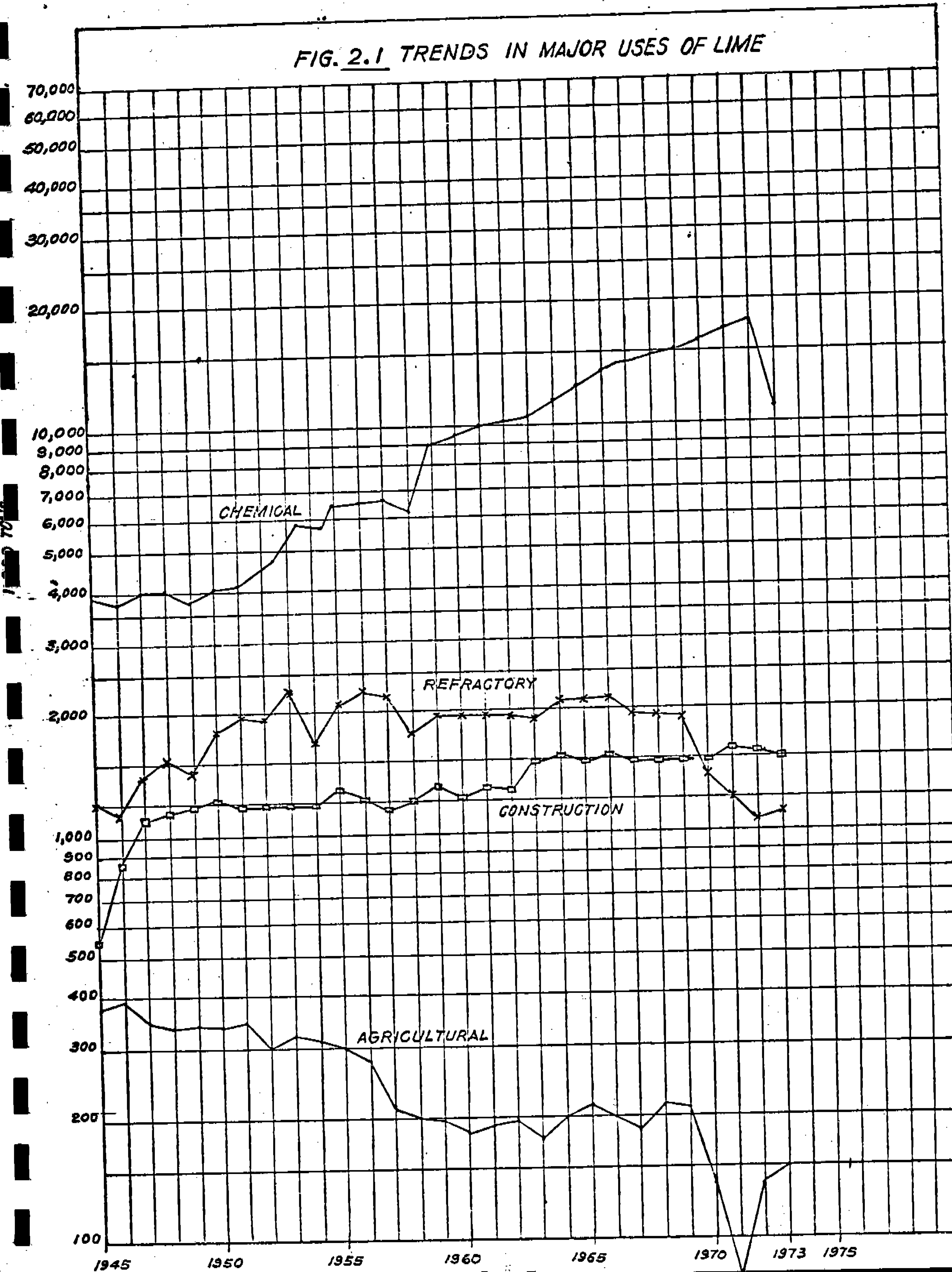

FIG. 2.1 TRENDS IN MAJOR USES OF LIME
70,000
60,000
50,000
40,000
30,000
20,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
900
800
700
600
500
400
300
200
100
CHEMICAL
REFRACTORY
CONSTRUCTION
AGRICULTURAL
1945
1950
1955
1960
1965
1970
1973
1975

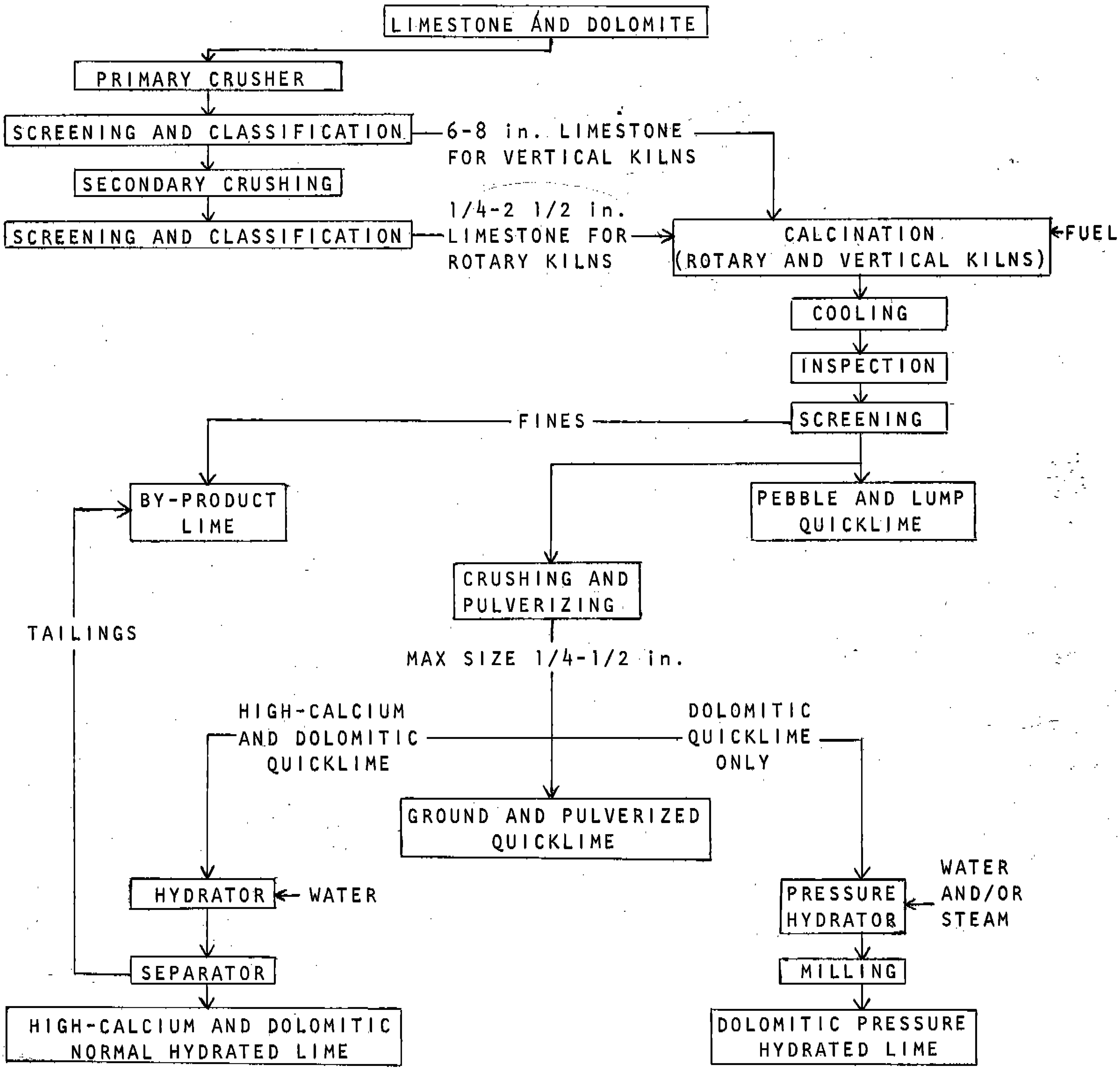

Fig. 2.2 SIMPLIFIED FLOWSHEET FOR LIME PRODUCTION (3)

Calcining at about 2000°F produces a soft, porous lime which is chemically highly reactive. Heating beyond this stage can result in lumps of inert, semivitrified material. This is known as "over-burned" or "dead burned" lime. This chemically 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. This is known as "underburned" lime.

In the United States, four types of kilns are used for the calcining of lime. They are: Rotary Kiln, Vertical Kiln, Rotary Hearth (Calcimatic) Kiln, and Fluidized Bed Kiln. Rotary kilns are predominant in the U.S., primarily because of their high production rate; however, rotary kilns are limited to small size stones (between 0.25 and 2.5 inch). Vertical kilns burn lump size limestone between 3 and 12 inches. The vertical kiln is also 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 accomodate a rather wide range of stone sizes, including relatively broad size distributions like 0.25 inch to 4 inch. The fluidized bed kiln, resembling a large vertical kiln, utilizes a fine particulate kiln feed of No. 8 to No. 65 mesh.

Of fourteen (14) known lime kiln installations made during the past five years, ten (10) were rotary kilns, three (3) were rotary hearth (calcimatic) kilns, and one (1) was a fluidized bed kiln. This appears to be the trend in the lime industry in the United States due to the high production capabilities of the rotary kiln and the rotary hearth kiln. Fluidized bed kiln installations are found primarily in areas where a friable grade of limestone is predominant along with the need for a high quality lime.

2.2 ROTARY KILN

In the United States, nearly 85% of commercial lime capacity and about 50% of captive lime is calcined in rotary kilns.[3] Rotary kilns achieve the highest production capacity of all kilns; the largest rotary kiln in operation in the United States is rated at 650 tons per day. The overall sizes of these kilns vary considerably, from 6 to 12 feet in diameter and from 60 to 450 feet 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 are equipped with heat-recuperative accessories such as kiln feed preheater and product cooler.[3]

A diagram of a rotary kiln is found in Figure 2.3. Rotary kilns are normally installed at a 3° to 5° inclination on four or six foundation piers and revolve at 30-50 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 to 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 into the kiln.

Sohpisticated dust collection is required for a rotary lime kiln. This dust collection is usually in the form of high efficiency water scrubbers, fabric filter (baghouse) collectors, or electrostatic precipitators.

2.3 VERTICAL KILN

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 in the U.S., the total capacity of the vertical kiln has fallen well behind that of the rotary kiln. Figure 2.4 is a schematic of a vertical kiln. This kiln can be described as an

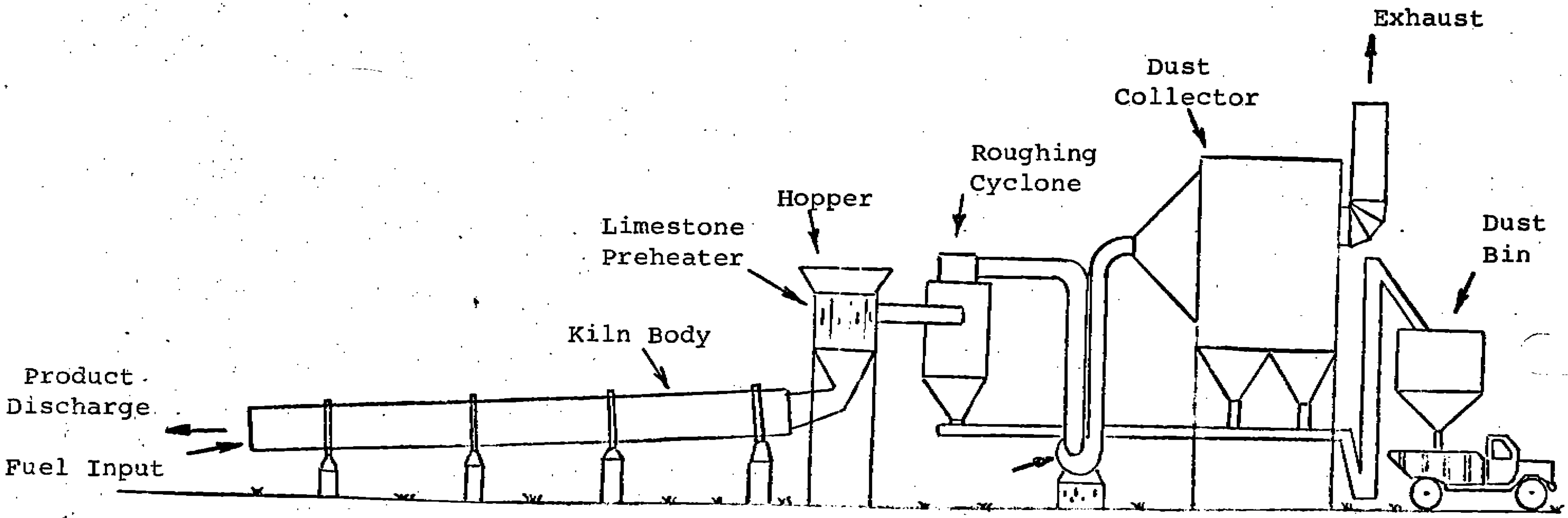

Fig. 2.3 Schematic Diagram of Rotary Kiln with Modern Collection System

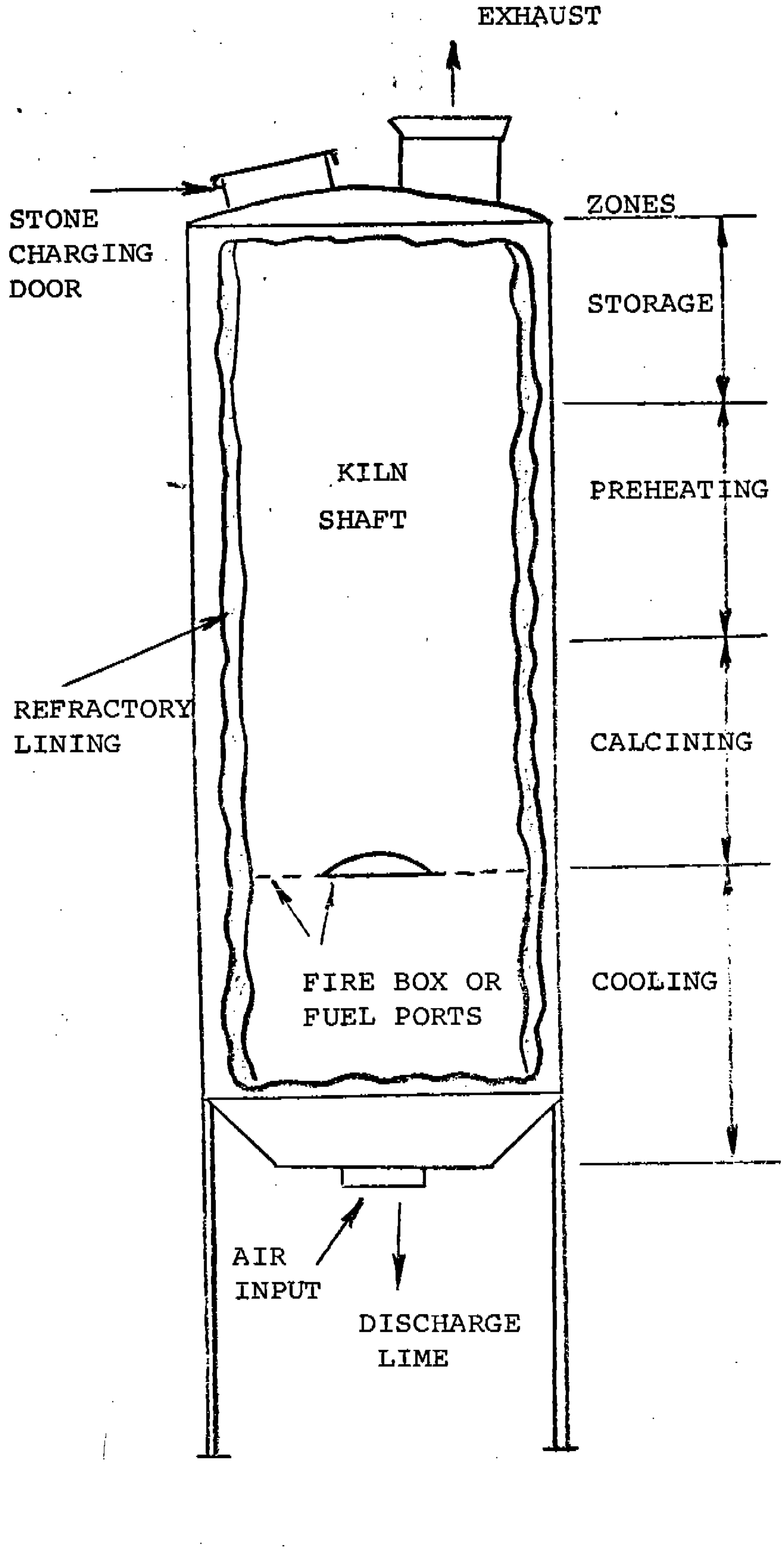

Fig. 2.4 Schematic Diagram of Vertical Kiln

upright heavy steel boiler plate cylinder lined with refractory material. The kiln is charged at the top with large lump-size limestone. This feed material is preheated in the upper sections of the kiln by the exhaust gases from the calcining zone. Kiln dimensions may vary from 8 to 25 feet in diameter and from 35 to 100 feet in height. Most modern vertical kilns average from 75 to 150 tons per day lime production. 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 in operation today in the United States have no dust collection equipment. This is attributed to the low dust production of the vertical kiln because:

1. Lump-size limestone feed into the kiln.
2. Slow movement of limestone through the kiln.

Of the fourteen (14) known lime kiln installations made since 1969, none were vertical kilns. This trend is found throughout the United States because of the high production requirements of domestic lime manufacturers.

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ENGINEERING CALCULATIONS

PAGE

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FOR TN-686

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UNIT

ESTIMATE OF TOTAL COAL USED BY LIME INDUSTRY

BASED ON PRODUCTION OF 21 MILLION TONS (1973 PRODUCTION)

$(21{,}000{,}000 \text{ TONS LIME})(70\% \text{ IN COAL FIRED KILNS}) = 14{,}700{,}000$ TONS LIME PRODUCED

$(14{,}700{,}000 \text{ TONS LIME})\left(\frac{1 \text{ TON COAL}}{3.37 \text{ TONS LIME}}\right) = 4{,}362{,}000$ TONS COAL

$\cong$ 4.4 MILLION TONS COAL

ESTIMATE OF N/G USED BY LIME INDUSTRY

$(21{,}000{,}000 \text{ TONS LIME})(27\% \text{ IN N/G FIRED KILNS}) = 5{,}670{,}000$ TONS LIME PRODUCED

$(5{,}670{,}000 \text{ TONS})\left(\frac{1 \text{ TON N/G}}{6.4 \text{ TONS LIME}}\right) = 885{,}937$ TONS N/G

ASSUME 886,000 TONS N/G

BASED ON SP. GRAVITY = .590 ; DENSITY = 22.6 ft^3/lb

$(886{,}000 \text{ TONS})\left(\frac{2000 \text{ lb}}{\text{TON}}\right)\left(22.6 \frac{ft^3}{lb}\right) = 4.005 \times 10^{10}$

4.0050000000. $\cong$ 40 BILLION ft^3 NATURAL GAS

2.4 ROTARY HEARTH KILN

The rotary hearth kiln, or "calcimatic" kiln is a circular shaped kiln with a slowly revolving donut-shaped hearth. Feed limestone is distributed in a one-to-six inch deep layer on this rotating calcining zone. The finished lime is scraped off about 350° around the circle from the point where the feed limestone is spread onto the hearth. The heated gases from the calcining zone of the kiln are passed through the feed limestone for preheat purposes, similar to the procedure in the vertical kiln. In some cases, the cooling of the burnt lime product is done in an indirect heat exchanger where the burner combustion air is preheated adding to the 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 accomodate 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 cyclone dust collectors.

2.5 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 tossed and bounced about by the turbulent air 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 characteristics of the fluidized bed process. Sophisticated dust collection equipment (such as venturi scrubbers, fabric filters, or electrostatic precipitators) is a necessity not only for air pollution considerations, but also for process economics.

There are presently three fluidized bed lime calciners in operation in the U.S.; one at the Brooksville, Florida plant of Chemical Lime, Inc., and two at the Adams plant of Pfizer, Inc. in Adams, Massachusetts. A fourth fluidized bed kiln is presently under construction at Pfizer, Inc.

2.6 KILN EMISSIONS COMPARISON

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 due primarily to the very small feed size combined with the high air flow through the kiln. The rotary kiln is second to the fluidized bed kiln in uncontrolled particulate emissions. This is attributed to the small feed size and dusting caused by rolling of the feed through the kiln. The rotary hearth or "calcimatic" ranks third in dust production, primarily because of the kiln's larger feed size combined with the fact that the limestone remains in a stationary position 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.

2.7 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 sized, 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, namely, chemical instability and structural unsoundness.[3]

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 40 to 100 psi is often employed when hydrating a dolomitic quicklime. 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 pre-mixer 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]

2.8 PROCESS FUELS

As pointed out in Section 2.1, the calcining of limestone is an endothermic reaction requiring heat. In the United States, three fuels are predominant in supplying the necessary energy for lime kilns. These fuels are coal, oil, and natural gas. The type of fuel used in a given kiln depends primarily on which fuel may be most easily obtained in the given location.

For example, in the Ohio-Pennsylvania region, the majority of the kilns are coal fired; while in Texas the majority of the kilns are natural gas fired. Many newer lime kiln installations and some older kilns have multiple burner set-ups whereby any or a combination of fuels may be used. This is most advantageous in areas where supplies of oil and/or natural gas may be curtailed.

The theoretical energy required to produce one ton of lime is 4.25 million BTU's.[1] In actuality, including heat losses, approximately 7.42 million BTU's are required to produce one ton of lime in a rotary kiln. The ratios of pounds of lime produced to pounds of fuel consumed for the three major fuels in a rotary kiln are:

1. 3.37 to 1.0 for bituminous coal[1] with an assumed heating value of 12,500 BTU per pound.
2. 5.04 to 1.0 for No. 6 grade fuel oil with a heating value of 153,000 BTU per gallon.
3. 6.4 to 1.0 for high methane natural gas with a heating value of 1,050 BTU per cubic foot.

3.0 EMISSION CONTROL TECHNOLOGY

Control equipment is available to efficiently reduce particulate emissions from all types of calcining and hydration processes used in the lime industry and to meet present state standards.

3.1 CALCINING EMISSION CONTROL

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 is non-reactive 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.[5]

As stated in Section 2.7, the ranking of lime kilns in terms of highest average dust emission to lowest average dust emission is:

1. Fluidized Bed Kiln
2. Rotary Kiln
3. Rotating Hearth (Calcimatic) Kiln
4. Vertical Kiln

A typical rotary kiln exhaust particle size distribution for an Ohio lime plant is shown in Table 3.1, page 20. It should be noted that the various percentages associated with the particle size distribution in Table 3.1 may change from state to state depending on the characteristics of the respective limestone deposit. It should also be pointed out that there is a significant percentage of "large" particles (larger than 32 microns) in this distribution. Often, these larger particles may be removed by a "rough" cleaning stage in which a low efficiency cyclone or similar device is used as a primary cleaning stage before a high efficiency emission control device.

Five types of emission control are found to be predominant in controlling dust emissions from lime kilns. These control systems are:

1. Fabric Filter "Baghouse" Collectors
2. Electrostatic Precipitators
3. High Pressure Drop Wet Scrubbers
4. Low Pressure Drop Wet Scrubbers
5. Cyclone or "Multiclone" Collectors

TABLE 3.1

TYPICAL ROTARY KILN EXHAUST
PARTICLE SIZE DISTRIBUTION
FOR AN OHIO LIME PLANT

Particle Size μ	% Weight	Cumulative % Weight
<1.2	1.0	1.0
1.2 - 2.0	2.2	3.2
2.0 - 4.4	9.5	12.7
4.4 - 7.7	11.1	23.8
7.7 - 11.8	10.4	34.2
11.8 - 20.8	16.4	50.6
20.8 - 27.5	6.6	57.2
27.5 - 32	3.2	60.4
>32	39.6	100.0

3.2 FABRIC FILTER "BAGHOUSE" COLLECTOR

The "baghouse" collector is the common name for a fabric filter collector. This system works by collecting dust in bag-shaped filters made of glass fiber cloths capable of withstanding temperatures up to 550°F. Since the kiln exhaust temperatures are higher than 550°F, gas cooling is required. It is achieved by (1) evaporative water sprays, (2) indirect radiation convection heat exchange by means of U-tube coolers, (3) ambient air dilution, or (4) a combination of these.

In order to maintain acceptable pressure drop values (usually less than 5" wg), the collected dust must be removed periodically. This is accomplished by isolating one of the compartments and collapsing or shaking the bags lightly with reverse gas flow. Each compartment is "off-line" for a nominal time of 2-5 minutes to complete the cleaning. This dust falls into a hopper during cleaning. The total dust load will control the time required between repeated cleaning of each compartment.

As one compartment is usually off-line for cleaning, the total available filtration area is reduced. Filter units are specified on the basis of air to cloth ratios (cfm of gas per sq. ft. of cloth) for the total unit and for one compartment

off-line for cleaning. Air to cloth ratios for lime kiln exhaust are nominally 2.2/1 when one compartment is off-line.[6]

The fabric filter collector has the primary advantage of offering the highest average collection efficiency (based on particle size, see Table 3.3, page 32) for lime kiln exhaust gas treatment. The collection efficiencies of the venturi scrubber and electrostatic precipitator are lower. The main disadvantages of the fabric filter collector are (1) large physical size space requirement; (2) relative high capital cost; and (3) high operating cost.

3.3 ELECTROSTATIC PRECIPITATOR

Precipitators for lime kiln application are of the dry, horizontal flow type construction common to many other applications. They are constructed of carbon steel, and therefore the kiln gas must be cooled to an acceptable level. Evaporative cooling is preferred because it results in a lower final gas flow and the moisture added may improve the dust precipitability.

The kiln gas enters the precipitator and flows through passages created by parallel rows of grounded collecting plates. Discharge electrode wires, supplied with 15,000 to 80,000 volts negative D.C. current, centered in each passage between a pair of the grounded plates charge the particles negatively. The ionized dust particles migrate toward the grounded collecting plates where they loose their charge and fall by gravity into hoppers. To assist in keeping the collector plates and discharge electrodes clean, programmed rapping of the electrodes is also required.

The efficiency of a precipitator is a function of the gas velocity and treatment time. Thus, higher efficiencies are attained in any process by increasing the precipitator size. Virtually any desired efficiency can be obtained, normally in the range of 90 percent to 99 percent.[6]

The primary advantages of the electrostatic precipitator are seen in cases where "dry" collector systems are required. In these instances, electrostatic precipitators require less space than do fabric filters. The operating costs are also found to be lower.

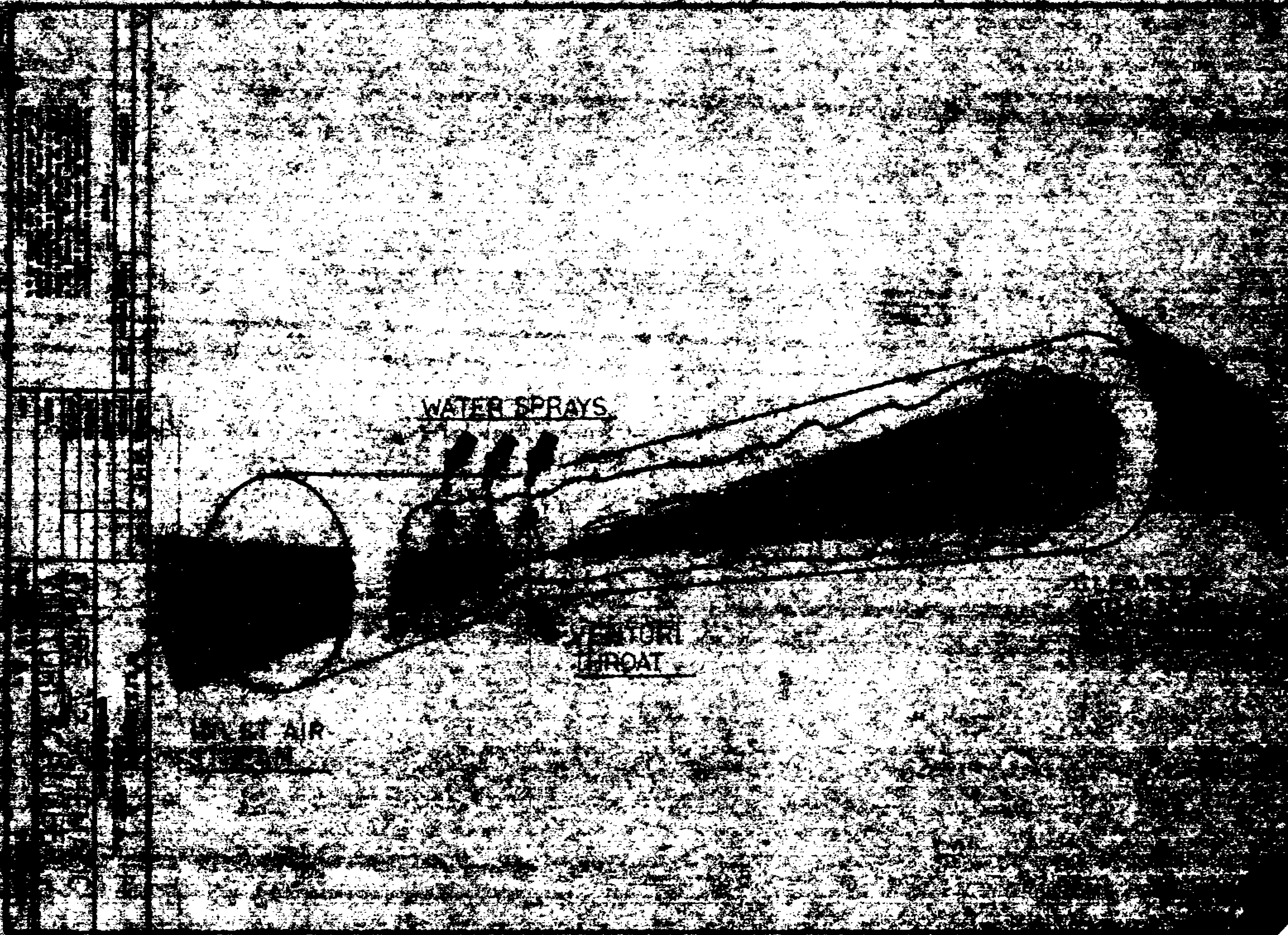
The major disadvantages of this collector are its high capital cost and its relatively low collecting efficiency on sub-micron particles. Also the capability of the dust particles to accept the negative charge is a requirement for an electrostatic precipitator installation. This capability is a function of the chemical composition of the dust particles.

3.4 WET SCRUBBERS

Wet scrubbers for the lime industry are often classified into two general types: (1) low pressure drop type, and (2) high pressure drop type. All scrubbers utilize water or other scrubbing liquid to condition small dispersed particles, to prevent particle re-entrainment, to assist particle disposal, to cool the gas stream, or all four.

The most common types of low pressure drop scrubbers are cyclone scrubbers and impingement scrubbers. The cyclone scrubber is a collector with centrally located coarse sprays, usually directed radially outward. The main purpose of the water is for gas cooling and to prevent re-entrainment. This is accomplished by slurrying and carrying away the material which is deposited on the wall by centrifugal force. The impingement scrubber is a baffled collector with water sprays to wet and flush the vertical baffles. The purpose of the water, as in the cyclone scrubber, is to prevent re-entrainment.

The most common high pressure drop scrubber used in the lime industry is the venturi scrubber, see Fig. 3.2, page 26. This scrubber consists of two tapered sections which form a throat in the air passage; water is injected into the air stream just ahead of or in the high velocity throat. The water


WATER SPRAYS

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ENGINEERING CALCULATIONS

FOR JN 686

PAGE

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CUSTOMER EPA STUDY UNIT BY

COVERAGE: 5 STATES ; 85 ROTARY KILNS
130 VERTICAL KILNS
5 ROTARY HEARTH (CALCIMATIC)

KILN	BAGHOUSE	CYCLONE	Hi Scr	Lo-Scr	ESP	NONE
ROTARY	20	8	26	11	7	13
VERTICAL	117	2	2	5	0	104
CALCIMATIC	1	1	3	–	–	–

KILN TYPE	FUEL	STATE	EMISSION DEVISE	COMMENT
Rot	Coal	OHIO JE Baker	Present - Settling chamber Proposed - Venturi Scrubber	comp 3/1/75
Rot	Coal	Ohio JE Baker	"	"
5 VERT	Coal	Ohio Cuyahoga	2 Mikro Pul Baghouse	7" ΔP ; 118,000 CFM @ 550°F
Rot	Coal	Ohio Basic	Present - Dust Chamber ESP - future	ESP to be 99%
Rot	Coal	"	"	"
Rot	Coal	"	"	"
Rot	Coal	"	"	"
Rot	N.G.	"	"	"
Vert	N.G.	"	PRESENT - NOTHING FUTURE = BAGHOUSE	BAGHOUSE TO BE 99.9 %
Vert	N.G.	"	"	
3 ROT	COAL N.G.	OHIO HURON LIME	HIGH ΔP SCRUBBERS	ΔP = 16" 99.9% EFF
ROT	COAL NG	OHIO MARTIN MARIETTA	CYCLONE @ 82.6%	1.9" ΔP / BAGHOUSE TO BE INSTALLED ON ALL THREE KILNS
ROT	COAL	"	"	"
ROT	COAL	"	"	"
CAL	N.G. OIL	OHIO NAT. GYP.	CALCIMATIC MULTICLONE	
15 VERT	N.G.	"	NONE	
CAL	N.G	OHIO NAT. CAREY	WET VENTURI	emission = 24 lb/Hr
CAL	N.G	"	BAGHOUSE	" = 20 lb/Hr
24 VERT	N.G.	OHIO OHIO LIME	NONE	emission = .72 lb/Hr.
Rot	Coal	"	WET Scrubber	61.6 #/Hr emission
Rot	"	"	NONE	
Rot	"	"	NONE	
Rot	"	"	NONE	
Rot	"	"	NONE	
Rot	Coal	Ohio REPUBLIC	ESP	99.7%
Rot	Coal	"	ESP	99.7%

KILN TYPE	FUEL	STATE	EMISSION DEVISE	COMMENT
2 VERT	N.G.	OHIO UNION CARBIDE	Cyclone Wet Scrubber	96.5 %
24 VERT	N.G.	OHIO U.S. GYPSUM	NONE	1.11 #/Hr ? #13 KILN
3 Rot	COAL N.G.	"	Spray Scrubber	99.7 % ? stated ea
2 VERT	N.G.	OHIO U.S. STEEL	Wet Scrubbers	99.6 % stated
Rot	OIL N.G.	OHIO Woodville	Roughing cyclone and ESP	1.83 #/Hr
Rot	OIL N.G.	"	ESP only	71.4 #/Hr
2 Rot	N.G	TEX Austin White	Ducon Scrubbers 16"⌀	99 %
6 VERT	N.G.	"	NONE	
Rot	N.G.	TEX - ROUND ROCK Dolomite Plt.	NONE	
2 VERT	N.G.	TEX, ARMCO Houston	NONE	
Rot	N.G.	TEX, Chemical Lime	Wet Scrubber	Scrubber @ 90%
4 ROT	N.G.	TEXAS TEXAS LIME CO.	Wet Scrubbers	all rated @ 99 %
Rot	N.G.	TEX McDonough Bro.	Venturi Scrubber	rated 99%
2 Rot	N.G.	TEX. U.S. GYPSUM	Ducon Scrubber	rated 98 %
10 VERT	N.G.	"	Baghouses	rated 99%
4 VERT	N.G.	TEX. PPG IND.	2 SCRUBBERS 2 BAGHOUSES	all High Eff.
Rot	N.G	TEX ALCOA	Venturi	high eff
Rot	N.G	"	Cyclone	
Rot	N.G	"	Baghouse	high eff
2 Rot	N.G	TEX DOW FREEPORT	2 ESP	99 %
Rot	N.G.	"	ESP	95 %

KILN TYPE	FUEL	STATE	EMISSION DEVISE	COMMENT
VERT	NG.	TEX DOW FREEPORT	Scrubber	85%
Rot	?	PENN. JE BAKER	Baghouse	rated @ 99.5%
Rot		PENN Bethlehem Hanover	high ΔP Scrubber	" @ 99%
5 Rot	Coal	PENN Bethlehem annville	Baghouse	rated @ 99%
6 VERT		Penn G&WH Corson	NONE	
Rot		"	Scrubber	
3 Rot		PENN. MARBLEHEAD	Cyclone on each	
Rot		PENN WARNER-CEDAR	Baghouse	rated @ 99%
Rot		"	Scrubber	rated @ 98%
Rot		PENN MERCER	Cyclone	94.8%
5 VERT		"	NONE	
3 Rot		PENN NAT. GYPSUM	Baghouse on each	99.9% rated

KILN TYPE	FUEL	STATE	EMISSION DEVISE	COMMENT
Rot	OIL NG	ALA ALLIED PROD	Venturi	high eff
Rot	COAL NG	ALA "	Venturi	"
Rot	COAL	ALA "	Venturi	"
3 Rot	COAL, OIL N/G	ALA MARTIN MARIETTA	Baghouses	AA Rated @ 99.9
2 Rot	COAL	ALA ALABASTER LIME	Zurn Scrubber	16" ΔP ~ 98.5%
Rot	Coal	ALA Cheney Lime	NONE	
2 Rot	COAL OIL N/G	ALA LONGVIEW	WET SCRUBBER	16" ΔP
2 VERT	N/G	MO. ASHGROVE	Ducon Dry Cyclone	
2 CAL	N/G	"	Ducon Wet Venturi	16" ΔP
Rot	COAL	MO. VALLEY MINERAL	Impingement Scrubber	included Particle size
6 Rot	COAL	MO. STE. GENEVIEVE	Baghouses (Peerless)	high eff.
8 Rot	COAL	"	4 high ΔP scrubbers 4 low ΔP scrubbers	95% 85%
20 VERT	12 COAL or OIL 8 N/G			WITHIN COMPLIANCE

EMISSION FACTOR DETERMINATION

$$E = \frac{P(ef)(1 - C_c)}{2000}$$

$$ef = \frac{E(2000)}{(P)(1 - C_c)}$$

where ef = emission factor
E = EMISSION RATE (TONS/YR)
P = PRODUCTION RATE (TONS/YR)
C_c = CONTROL EQPT EFFICIENCY

FOR SAMPLING OF LIME KILNS SURVEYED HAVING CONTROL EQUIPMENT INSTALLED, OPERATING AT EFFICIENCY OF 99 %

P = 3,821,400 TONS/YR
E = 2903 TONS/YR
C_c = 98.5 %

$$ef = \frac{\left(2903 \frac{TONS}{YR}\right)\left(2000 \frac{lb}{TON}\right)}{\left(3821400 \frac{TONS\ PROD.}{YR}\right)(1 - .985)} = \frac{(2903)(2000)}{(3,821,400)(.01)}$$

$$ef = 152 \frac{lb}{TON}$$

PERCENTAGE PRODUCTION CAPACITY HAVING CONTROL EQUIPMENT

TOTAL PRODUCTION ON 18 UNCONTROLLED KILNS - 1,091,262 TONS
TOTAL PRODUCTION ON 71 CONTROLLED KILNS - 7,164,065
8255327

STATE	UNCONTROLLED PROD.	CONTROLLED PROD
OHIO	581,065	1,667,900
TEXAS	38,965	885,765
PENNSYLVANIA		
ALABAMA		
MISSOURI		

PERCENTAGE OF PRODUCTION EQPT WITH CONTROL EQPT.

$$\frac{7,164,065 \text{ TONS}}{8,255,327 \text{ TONS}} = 86.8\%$$

ESTIMATED NATIONWIDE EMISSION

$$E = \frac{P(ef)(1 - C_c C_t)}{2000}$$

where
- E = EMISSION RATE, TONS/YEAR (FROM ROTARY KILNS)
- ef = EMISSION FACTOR, lb/TON
- P = PRODUCTION RATE, TONS/YEAR (ROTARY KILNS)
- C_c = AVE OPERATING EFFICIENCY OF CONTROL EQPT.
- C_t = PERCENTAGE OF PRODUCTION CAPACITY ON WHICH CONTROL EQPT HAS BEEN INSTALLED.

P_T = PRODUCTION RATE FOR 1975 = 21,050,000 TONS TOTAL

$$P = (.84)P_T = (.84)(21{,}050{,}000) = 17{,}682{,}000 \text{ TONS}$$

$$E = \frac{\left(17{,}682{,}000 \frac{\text{TONS}}{\text{YR}}\right)\left(1 - (95\%)(87\%)\right)\left(152 \frac{\text{lb}}{\text{TON}}\right)}{2000 \frac{\text{lb}}{\text{TON}}}$$

$$E = \frac{(17{,}682{,}000)(1 - (.95)(.87))(152)}{2000} = \frac{(17{,}682{,}000)(.17)(152)}{2000}$$

E = 228,450 TONS/YEAR TOTAL FROM ROTARY KILNS

DETERMINE AVERAGE EFFICIENCY OF CONTROL DEVICES USED:

9	CYLONES @ 85%	765
18	BAGHOUSES @ 99%	1782
6	ESP's @ 99%	594
33	Hi-ΔP SCRUBBERS @ 98.5%	3250.5
5	Lo-ΔP SCRUBBERS @ 75%	375

OVERALL AVERAGE FOR 71 CONTROL DEVISES = 95.3%

DETERMINE EMISSION FACTOR FOR ROTARY KILN

PAGE	E.F.	TOTAL PROD		Ratio	TOTAL EMISSION (@ Hi-EFF REMOVAL)
1	190	348,000	40	2.19×10^{-4}	76.5 @ 99%
2	210	217,000	25	4.8×10^{-4}	105. @ 98%
3	72	610,900	70	8.23×10^{-5}	50.3 @ 99%
4	275	523,800	60	3.14×10^{-4}	164.9 @ 99%
5	~~[illegible]~~	—			—
6		~~375,000~~			~~604 @ 85%~~
7		~~86,400~~			~~104 @ 94.9%~~
8	[illegible]	635,000	72	1.86×10^{-4}	118.4 @ 98.5
9	[illegible]	999,500	114	1.26×10^{-4}	126.8 @ 99%
10	38	487,200	56	6.15×10^{-5}	30.+ @ 98.5
	AVG = 143	3,821,400			671.9 lb/hr

1.000 − .985 = .015

2902.6 TON/YEAR

may be introduced by means of an overflow or through nozzles or slots and is broken up into fine droplets by the action of the high velocity gas stream. The dispersed material in the dirty gas stream is deposited on the water droplets in the throat. Gas-water contact in the venturi is so thorough that even the submicron particles are removed. The degree of cleaning is a direct function of the energy input, which is reflected by the pressure drop across the venturi throat. Throat pressure drop ranges from 8" W.C. to 40" W.C. depending upon the particle size and the degree of cleaning. The water requirements are in the range of 5 to 10 gallons per 1,000 CFM of gas.

Downstream of the venturi, the droplets coalesce so that a comparatively simple device such as a cyclone scrubber may be used for collection.[8]

The primary advantages of the venturi scrubber are its small space requirement, its relative low capital cost and operating cost.

The primary disadvantages of this scrubber are: (1) care must be taken to prevent caking and plugging of the venturi throat; (2) secondary treatment is required for removing the particulate from the scrubber water; (3) problems often arise on scrubber installations in areas of freezing climate.

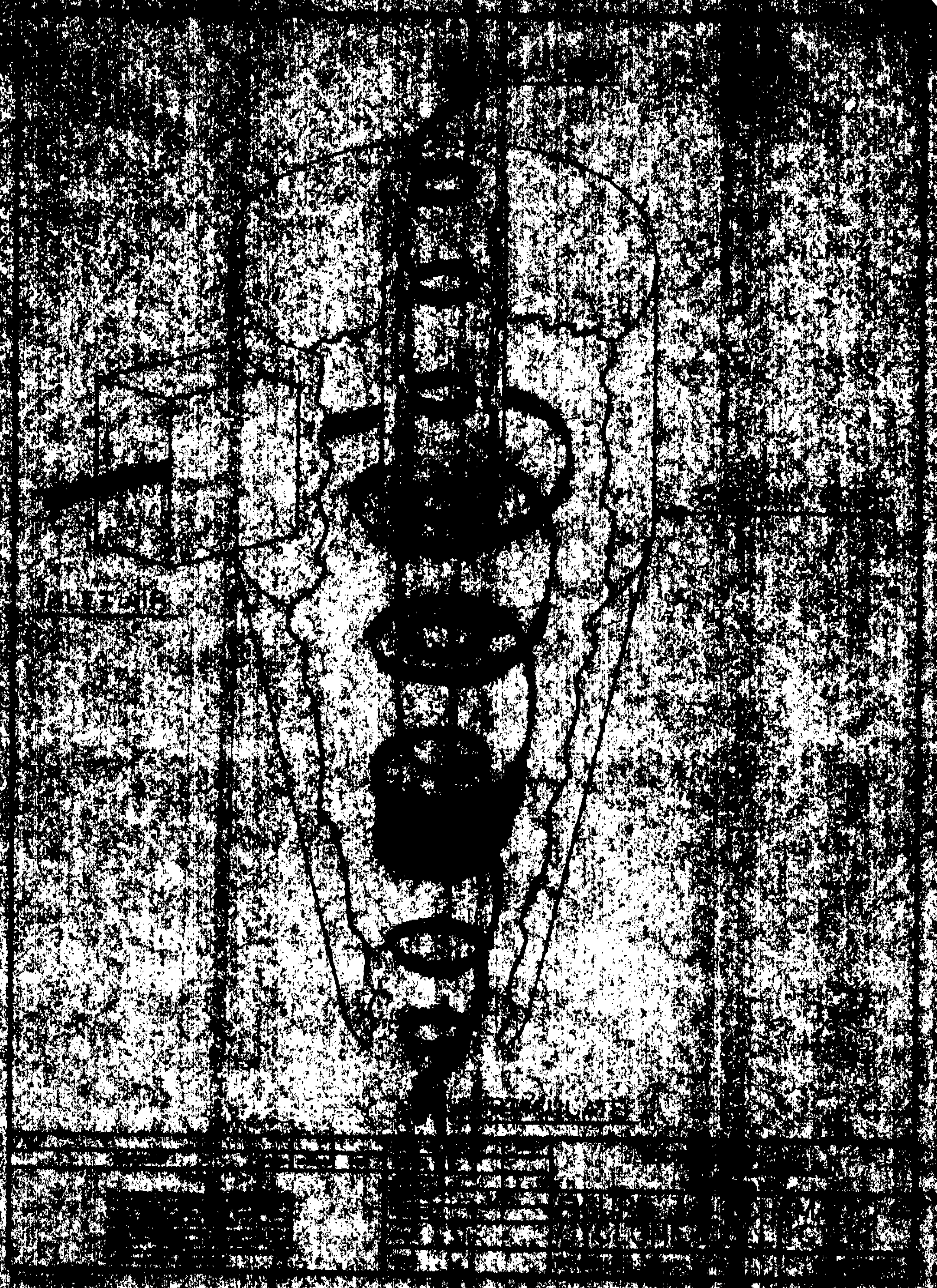
3.5 DRY COLLECTORS

The general category of "dry inertial collectors" includes the settling chamber, baffle chamber, cyclone and multiple cyclone separators.

A settling chamber may be no more than a long straight bottomless horizontal duct over a hopper or it may consist of a group of horizontal passages formed by shelves in a chamber. In the settling chamber, the gas flow rate is reduced to a velocity which allows the dispersed material to be removed by settling action. The settling chamber is effective only for particles above 100 micron in size. Overall efficiencies range from 0-30%.

A baffled chamber may be simply a box with horizontal entry and exit and one or more vertical baffles to induce reversed air flow and permit entrained particles to strike the baffles by inertia and fall to the hopper below.[8] The efficiency range of the baffle chamber is roughly the same as the settling chamber.

The cyclone dust collector is designed for tangential entry of the gas stream into the cylindrical section which imparts a swirling or circular motion to the gas. The particles in gas stream are thrown to the wall of the cylinder and out of the



gas stream by centrifugal force. The lower section of the cyclone separator is tapered which imparts higher velocities to the gas and separates smaller particles. A centrally located pipe permits discharge of the clean gas stream through the top of the separator. The solids drop down the wall and are collected in a chamber below.

The collection efficiency is dependent upon the cyclone pressure drop (a function of the velocity squared) and is limited by the particle size. Normally the pressure drop is in the range of 2" W.C. to 6" W.C. and efficiencies to 85% for 3 micron and larger particles are possible.

The advantages of the cyclone are its low cost, simplicity of maintenance (no moving parts), and low space requirement. Its disadvantage is the limited efficiency for removal of submicron particles.

Table 3.2 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. In the five rotary hearth installations, three are controlled by high pressure drop scrubbers, one is controlled with a "baghouse" type collector, and one is controlled with a multiclone type collector. All five rotary hearth kilns are operating within respective state regulations.

TABLE 3.2

EMISSION CONTROL ON 89 ROTARY LIME KILNS

Control Device	No. in Operation	%
Cyclone	9	10.1
Baghouse	18	20.2
E.S.P.	6	6.8
Hi ΔP Scrubber	33	37.1
Lo ΔP Scrubber	5	5.6
None	18	20.2
Total	89	100.0

Of the five collectors predominantly used on lime kilns, three are found to be capable of successfully meeting state air pollution standards on all types of lime kiln installations. These are baghouse collectors, electrostatic precipitators, and high pressure drop wet scrubbers.

Table 3.3 "Efficiency of Dust Collectors"(7) summarizes the average efficiencies of dust collectors used in the lime industry.

TABLE 3.3

EFFICIENCY OF DUST COLLECTORS

Collector	Eff. at 5 μ (%)	Eff. at 2 μ (%)	Eff. at 1 μ (%)
High Efficiency Cyclone	73	46	27
Irrigated Cyclone	87	60	42
Spray Tower	94	87	55
Venturi Scrubber	99.8	99	97
Fabric Filter	99.8	99.5	99
Electrostatic Precipitator	99	95	86

Source: "Processes for Air Pollution Control;" G. Nonhebel, CRC Press; 1972.

3.6 HYDRATION EMISSION CONTROL

As pointed out in Section 2.6, hydration emissions are most effectively controlled by the use of water sprays or wet scrubbers. In either method, the water effluent from the cleaning device is supplied to the hydrator's pre-mixer as part of the slaking water. In this manner, all hydrated lime losses are averted along with the need for secondary treatment of the scrubber effluent water.

Associated with lime hydration normally 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, and bagging processes, and on associated transfer points in the system.

3.7 FOREIGN LIME EMISSION CONTROL

Six responses are available out of ten questionnaires sent to foreign companies manufacturing lime. The list of foreign manufacturers was supplied to Vulcan-Cincinnati by the National Lime Association, Washington, D. C., Robert S. Boynton, Executive Director. The responding foreign companies are listed in Table 3.4, page 34. Actual data from foreign manufacturers are listed in Table 3.5, page 35. Examination of the responses reveals emission control techniques used abroad to be very similar to those used in the United States with the exception that the use of gravel bed filters was noted in two of the six responding companies.

August 30, 1974

TABLE 3.4

FOREIGN LIME PLANTS

Company No.	Company
1	Establissement Leon L'Hoist 20, Boulev d'Avroy, Liege, Belgium
2	S.A. Carrieres et Fours a Chaun Dumont - Wautier 4143 Hermalle - Sous - Huy (Brussels) Belgium
3	Alkali Division Imperial Chemical Industries, Ltd. Buxton Lime Works Royal Exchange, Buxton Derbyshire, England
4	Reinisch - Westfalische Kalkwerke 5601 Dornapm Rhinelond, West Germany
5	-Rheinische Kalksteinwerke- GmbH 5603 Wulfrath, West Germany Wilhelmstrasse 77
6	Ashidachi Lime Co., Ltd. CPO Box 1170 Osaka, Japan

TABLE 3.5

CONTROL TECHNIQUES IN FOREIGN LIME PLANTS

Company No.	Plant Size Metric Tons	Kilns	Control Equipment	Emission	Comment
1	300,000	5-Vertical	Cyclone	15. gr/scf ea.	Gravel bed filter to be installed as supplement.
		1-Calcimatic	Cyclone	-	Baghouse to be installed as supplement.
		2-Rotary	Fabric Filter	.05 gr/scf ea.	
2	140,000	1-Vertical	Cyclone w/Gravel Bed	.15 gr/scf	
		1-Rotary	ESP	.07 gr/scf	
3	270,000	3-Calcimatic	Cyclones	.2 gr/scf	Four cyclones per kiln.
4	700,000	12-Vertical	Cyclone w/Wet Scrubber	- .02 gr/scf ea.	 Only eight of twelve kilns are controlled.
5	2,165,000	19-Vertical	Fabric Filter Wet Scrubber	-	4 Vertical Kilns. 3 Vertical Kilns.
		4-Rotary	ESP	-	All four Rotary Kilns.
6	130,000	2-Rotary	Fabric Filter	.01 gr/scf ea.	

4.0 ENVIRONMENTAL EFFECTS

The major impact on the environment from the lime industry is air pollution. The effects of water pollution and solid waste pollution are relatively insignificant.

The impact of the energy required to operate the control equipment for a lime kiln is a small percentage of the total energy required to operate the entire plant.

4.1 IMPACT ON AIR POLLUTION

The primary air pollution concern from the lime industry is that of particulate emission. For a sampling of rotary lime kilns in the five state survey, covering approximately 45% of the total U.S. lime industry, the average emission factor was 152 pounds particulate per ton of lime produced. Average control efficiency for 71 emission control devices on rotary lime kilns surveyed in the five state study was 95%. The percentage of rotary lime kiln production having control equipment was 87%. Table 4.1, page 37, presents the estimated nationwide emission from rotary lime kilns based on 1973 lime production.

In Figure 4.1, page 38, this information is displayed graphically for various levels of control efficiency with different percentages of rotary kilns having control equip-

TABLE 4.1

ESTIMATED NATIONWIDE EMISSION FROM ROTARY LIME KILNS

The emission factor method of determining emissions is based on the following equation:

$$E = \frac{P(ef)(1-C_c C_t)}{2000}$$

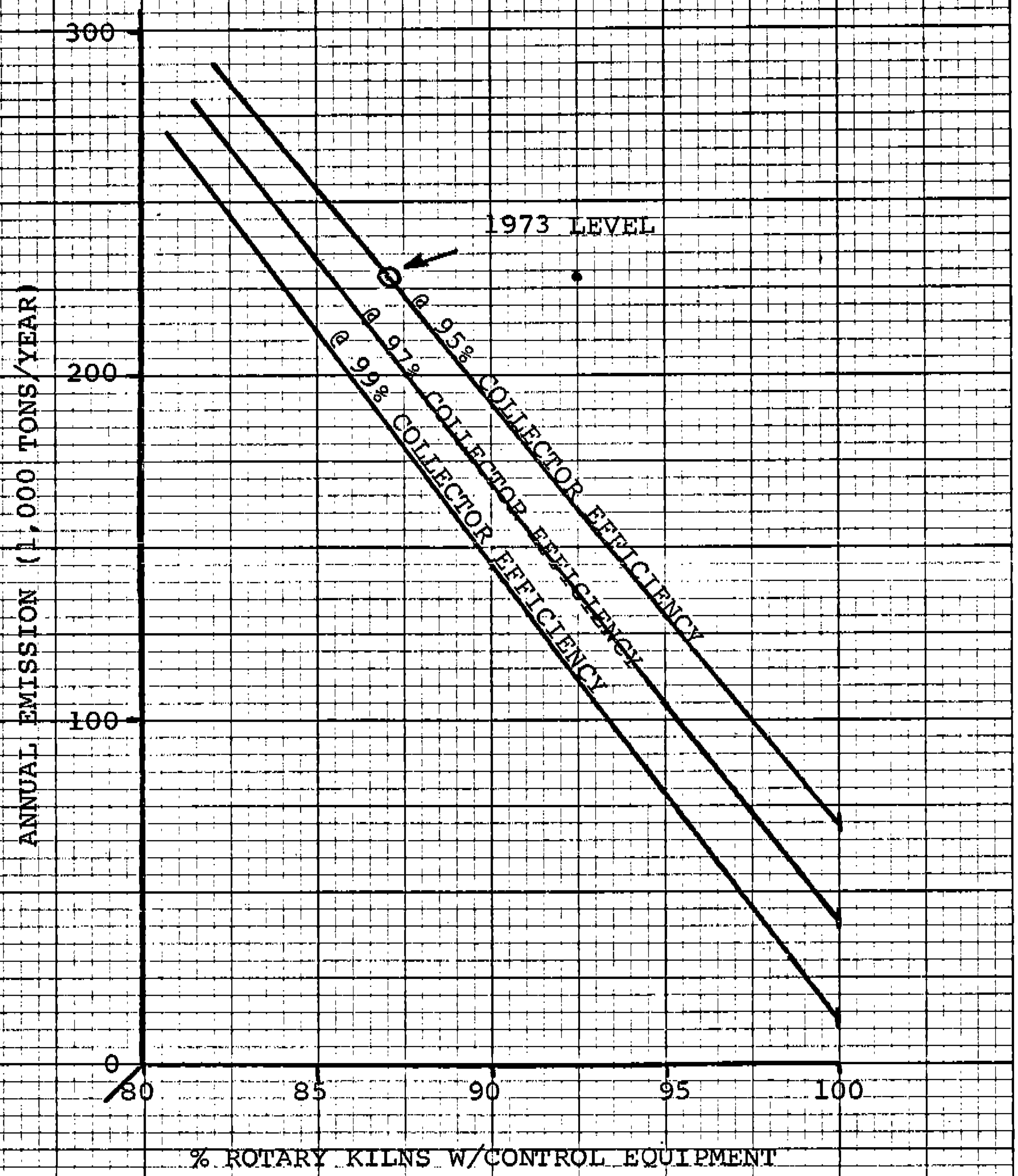
where

- E is the emission rate, tons/year
- ef is the emission factor (uncontrolled), lb/ton
- P is the production rate, tons/year
- C_c is the average operating efficiency of control equipment
- C_t is the percentage of production capacity on which control equipment has been installed

Item	Rotary Lime Kilns
ef	152 lb/ton
P	17,682,000 tons/year
C_c	95 percent
C_t	87 percent

Total Particulate Emissions from Rotary Lime Kilns = 228,450 tons per year

Fig. 4.1 ANNUAL EMISSION AT VARIOUS CONTROL EFFICIENCIES FOR ALL U.S. ROTARY LIME KILNS (Based on 1973 Production)



ment. For example, Figure 4.1 shows that if 90% of all rotary kilns had control devices which were 99% efficient, the total annual rotary kiln emission would be 145,000 tons of particulate (based on 1973 production).

4.2 IMPACT ON WATER POLLUTION

The impact of the lime industry on water pollution results from the use of water scrubbers for removal of particulates from exhaust air streams from kilns, hydrators, and transfer points in the manufacture of lime. Fabric filters and electrostatic precipitators have no impact on U.S. water pollution.

In considering water effluent emissions from scrubbers installed on hydrator stacks, it has been pointed out that virtually all efficient hydrators use scrubber water effluent as the slaking water for the hydrator.

In considering water effluent from scrubbers installed on lime kilns, primarily all lime plants using scrubbers discharge their effluent water into a settling pond or evaporation pond. In this way, the particulate is allowed to settle to the bottom of the pond while the water is either lost through evaporation or pumped back as the feed water for the scrubber. Periodically, the pond must be dredged to remove the build-up or particulate material. This material is then normally dumped into an unused area of the lime plant's quarry.

Through the use of the above methods of scrubber water disposal, pollution of water streams within the area of the lime plant is avoided. The previously mentioned survey of the lime industry in the states of Ohio, Texas, Pennsylvania, Missouri and Alabama revealed no incidents of water pollution resulting from scrubber water effluent. Inspection of lime plants in Missouri and Texas confirmed scrubber water being disposed in the above described manner.

4.3 IMPACT ON SOLID WASTE POLLUTION

Solid waste discharge from lime manufacturing is in the form of material collected by baghouse collectors, electrostatic precipitators, cyclone collectors, and material dredged from wet scrubber settling ponds. This solid waste material may be divided into two classifications:

1. Material suitable for production purposes.
2. Material not suitable for production purposes.

Material suitable for production may be either calcium carbonate particulate (or calcium magnesium carbonate) that may have been exhausted from the preheat section of a kiln, or calcium oxide (or calcium magnesium oxide) that may be exhausted from a kiln product cooler. The primary consideration which must be given to particulate exhausted from the preheat section of a kiln is the sulfur content of the kiln fuel. If a high sulfur content fuel is used, the calcium oxide portion of the particulate may have adsorbed too much sulfur oxides to allow its use as a feed limestone material. If a low sulfur fuel is used, such as natural gas, this particulate from the preheat section of the kiln is sometimes re-used as a feed material into the kiln. Some lime manufacturers have reported success in "briqueting" this particulate before re-use. Particulate exhausted from a kiln product cooler is often found to be high quality calcium oxide (or calcium magnesium oxide). In such a case, this material may be milled, and/or sold as quicklime, or hydrated prior to sale.

Material not suitable for production may be particulate collected from a kiln using a high sulfur fuel, or material dredged from a settling pond. This material normally is dumped into an unused area of the lime plant's quarry. In this manner off-site disposal of the lime plant's solid waste is avoided.

4.4 IMPACT ON ENERGY CONSIDERATIONS

The three major control devices used for controlling emissions from lime kilns have different power requirements. These requirements for three sizes of control devices are shown in Table 4.2, page 43. The 35,000 ACFM unit would be applicable for a 125 ton per day rotary kiln; the 85,000 ACFM would be applicable for a 250 ton per day rotary kiln; and the 150,000 ACFM would pertain to a 500 ton per day rotary kiln. The electrostatic precipitator is found to have the lowest power requirement; the high efficiency scrubber is second; and the fabric filter is the highest in power consumption.

Also included in Table 4.2 is the power requirement for calcining for the various sizes of rotary lime kilns. This does not include the power required for the associated conveyors and drives. The power requirement of the emission control device is small when compared to the energy requirement of the calcining operation.

TABLE 4.2

ENERGY REQUIREMENTS OF ROTARY LIME KILNS AND VARIOUS EMISSION CONTROL DEVICES

Equipment Item	POWER REQUIREMENT (KW) Air Flow and Plant Capacity (Tons/Day) 35,000 ACFM 125 T/D	85,000 ACFM 250 T/D	150,000 ACFM 500 T/D
Electrostatic Precipitator	53	101	134
High Efficiency Scrubber	45	104	183
Fabric Filter	45	112	224
Rotary Lime Kiln (Calcining Only)	11,300	22,600	45,200

Source: "Study of Technical and Cost Information for Gas Cleaning Equipment in The Lime and Secondary Non-Ferrous Metallurgical Industries;" Industrial Gas Cleaning Institute; December, 1970.

5.0 EMISSION CONTROL COST CONSIDERATIONS

In Section 4.4, energy requirements of the three major emission control devices were analyzed. Tables 5.1, 5.2 and 5.3 present cost information for the high efficiency scrubber, fabric filter and electrostatic precipitator. These costs are based on the necessary control equipment that would meet a .03 grains per standard cubic foot emission requirement. It should be noted that in terms of both equipment cost and installation cost, the scrubber is found to be lowest, followed by the fabric filter, and the electrostatic precipitator.

5.1 ECONOMIC IMPACT

In Tables 5.4, 5.5 and 5.6 a cost impact analysis is made for installation of each of the three major high efficiency control devices on either a small, medium, or large rotary kiln. In this analysis, straight line depreciation of the cost of the control equipment over its expected life was used. Examination of these tables reveals the high efficiency scrubber to have the least effect on the manufacturing costs of quicklime, with the electrostatic precipitator having a slightly greater effect, and the fabric filter having the greatest impact on manufacturing cost.

TABLE 5.1

WET SCRUBBER COST DATA
FOR ROTARY LIME KILNS

INFORMATION	WET SCRUBBER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	125	250	500
Inlet Gas Volume, ACFM	35,000	85,000	150,000
Efficiency, Wt. %	99.4	99.4	99.4
Controlled Emission, gr/ACF	0.03	0.03	0.03
Type of Charge	Limestone	Limestone	Limestone
Inlet Gas Temperature, °F	1,200	1,200	1,200
System Horsepower	60	140	245
Equipment Cost, $			
A. Collector	14,300	25,800	44,700
B. Auxiliaries	9,250	12,600	16,700
C. Gas Conditioning Equipment			
D. Waste Equipment			
E. Other			
Total	23,550	38,400	61,400
Total Installation Cost, $	48,900	66,300	86,900
Expected Life, Years	10	10	10
Operating and Maintenance, $/year	4,800	5,600	6,500

Source: "Study of Technical Cost Information for Gas Cleaning Equipment in the Lime and Secondary Non-Ferrous Metallurgical Industries;" Industrial Gas Cleaning Institute, Inc.; Dec. 1970.

TABLE 5.2

FABRIC FILTER COST DATA
FOR ROTARY LIME KILNS

INFORMATION	FABRIC FILTER		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/day	125	250	500
Inlet Gas Volume, ACFM	20,000	50,000	90,000
Efficiency, Wt. %	99 Plus	99 Plus	99 Plus
Controlled Emission, gr/ACF	0.03	0.03	0.03
Type of Charge	Limestone	Limestone	Limestone
Inlet Gas Temperature, °F	550	550	550
System Horsepower	Hot 60 Cold 111	150 300	300 600
Equipment Cost, $			
A. Collector	53,250	75,620	106,515
B. Auxiliaries	10,480	17,910	27,840
C. Gas Conditioning Equipment	3,740	4,675	6,440
D. Waste Equipment	18,610	20,680	23,250
E. Other	6,610	11,890	16,405
Total	94,690	130,775	180,450
Installation Cost, $	75,750	100,695	135,340
Expected Life, Years	20-25	20-25	20-25
Operating and Maintenance, $/year	11,000	18,000	30,000

Source: "Study of Technical Cost Information for Gas Cleaning Equipment in the Lime and Secondary Non-Ferrous Metallurgical Industries;" Industrial Gas Cleaning Institute, Inc.; Dec. 1970.

TABLE 5.3

ELECTROSTATIC PRECIPITATOR COST DATA
FOR ROTARY LIME KILNS

INFORMATION	ELECTROSTATIC PRECIPITATOR		
	SMALL	MEDIUM	LARGE
Process Capacity, Ton/Day	125	250	500
Inlet Gas Volume, ACFM	24,500	59,500	105,000
Efficiency, Wt. %	99.4	99.3	99.3
Controlled Emission, gr/ACF	0.03	0.03	0.03
Type of Charge	Limestone	Limestone	Limestone
Inlet Gas Temperature, °F	700	700	700
System Horsepower Fan (3" Wg)	12	30	50
Precip. HVPS*	59	105	129
Equipment Cost, $			
A. Collector	68,200	79,400	102,500
B. Auxiliaries	57,800	72,600	85,000
C. Gas Conditioning Equipment	12,350	29,500	51,500
D. Waste Equipment			
E. Other			
Total	138,350	181,500	239,000
Installation Cost, $	76,900	109,100	155,200
Expected Life, Years	20	20	20
Operating and Maintenance, $/year	2,000	2,000	3,000

* High Voltage Power Supply, figured as horsepower equivalent.

Source: "Study of Technical Cost Information for Gas Cleaning Equipment in the Lime and Secondary Non-Ferrous Metallurgical Industries;" Industrial Gas Cleaning Institute, Inc.; Dec. 1970.

TABLE 5.4

IMPACT OF SCRUBBER INSTALLATION
ON QUICKLIME COST

INFORMATION	ROTARY LIME KILN		
	Small	Medium	Large
Production Output (ton/day)	125	250	500
Scrubber Initial Cost*, $	86,940	125,640	177,960
Scrubber Expected Life (years)	10	10	10
Scrubber Cost per year**, $	8,694	12,564	17,796
Scrubber Operating Cost/year*, $	5,760	6,720	7,800
Total Scrubber Cost, $	14,454	19,284	25,596
Assumed Annual Lime Production (tons)	43,750	87,500	175,000
Cost of Scrubber per ton of Lime Produced, $	.33	.22	.15
Present Avg. Selling Price of Quicklime per ton***, $	18.75	18.75	18.75
Percentage Increase in Quicklime Selling Price to absorb cost of Scrubber, %	1.8	1.2	.8

* 1970 cost updated to January, 1974 using "Chemical Engineering Plant Cost Index," January 7, 1974.

** Assuming straight line depreciation.

*** "Chemical Marketing Reporter;" February 11, 1974.

TABLE 5.6

IMPACT OF ELECTROSTATIC PRECIPITATOR INSTALLATION ON QUICKLIME COST

INFORMATION	ROTARY LIME KILN		
	Small	Medium	Large
Production Output (ton/day)	125	250	500
ESP Initial Cost*, $	258,300	348,720	473,040
ESP Expected Life (years)	20	20	20
ESP Cost per year**, $	12,915	17,440	23,650
ESP Operating Cost/year*, $	2,400	2,400	3,600
Total ESP Cost, $	14,315	19,840	27,250
Assumed Annual Lime Production (tons)	43,750	87,500	175,000
Cost of ESP per ton of Lime Produced, $	.35	.23	.16
Present Avg. Selling Price of Quicklime per ton***, $	18.75	18.75	18.75
Percentage Increase in Quicklime Selling Price to absorb cost of ESP, %	1.9	1.2	.9

* 1970 costs updated to January, 1974 using "Chemical Engineering Plant Cost Index;" January 7, 1974.

** Assuming straight line depreciation.

*** "Chemical Marketing Reporter;" February 11, 1974.

6.0 ALTERNATIVE STANDARDS

Of the 89 rotary lime kilns evaluated in the five state survey, 62 percent of the these kilns were found to be in compliance with state regulations regarding particulate emissions. In Table 6.1, page 52, a comparison is made of emissions from the 89 rotary lime kilns studied to possible new source standards. It should be pointed out that percentages shown in this table are based on wet standard cubic feet, since the moisture contents of the individual air streams were not available. From Table 6.1, 62 percent of the rotary lime kilns evaluated could meet a standard of .1 grain per standard cubic foot; while 38 percent could meet a standard of .05 grains per standard cubic foot; and 31 percent could meet a standard of .03 grains per standard cubic foot.

TABLE 6.1

COMPARISON OF PROPOSED NEW SOURCE STANDARDS TO EXISTING ROTARY LIME KILN EMISSIONS

State	Rotary Kilns Studied	Rotary Kilns Meeting Present State Codes		Percent Rotary Kilns Meeting Possible Standards (Gr/SCF)					
		No.	Percent	.1	.07	.05	.04	.03	.02
Ohio	27	12	44	37%	33%	26%	22%	22%	22%
Pennsylvania	17	11	65	82%	82%	71%	59%	59%	12%
Texas	17	15	88	82%	53%	47%	47%	47%	35%
Missouri	17	12	71	71%	65%	50%	50%	33%	33%
Alabama	11	5	45	45%	45%	9%	9%	0	0
Total	89	55	62	62%	54%	38%	35%	31%	20%

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Fig. A.1

LIME PLANTS THROUGHOUT THE UNITED STATES

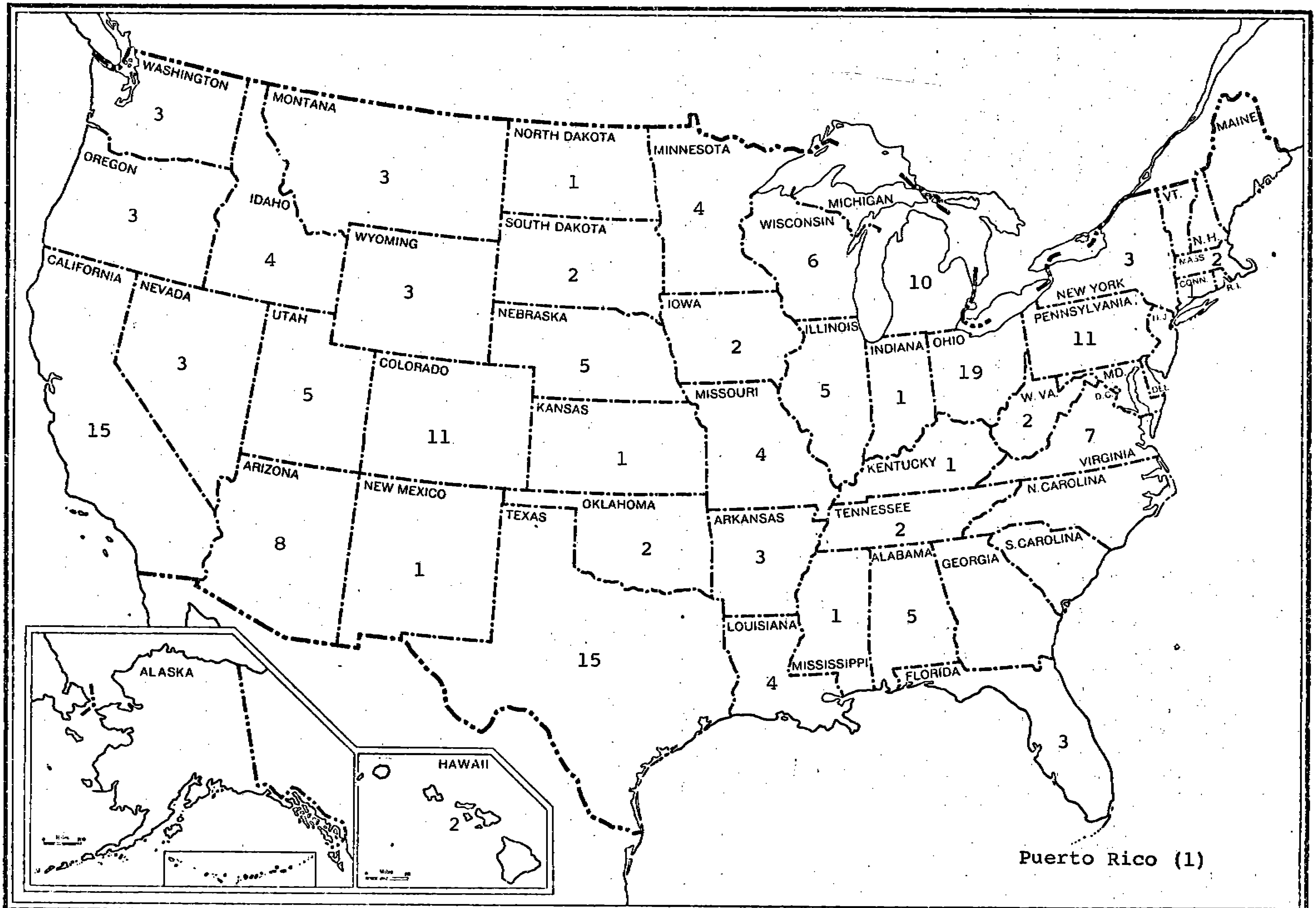

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TABLE A.1

LIME PLANTS IN THE UNITED STATES

Location	Company and Plant Name	Address
Alabama	Alabaster Lime Co. Scotrock Plant	Siluria, AL 35144 Shelby County
Alabama	Allied Products Co. Calera Plant	Drawer 1 Montevallo, AL 35115
Alabama	Cheney Lime & Cement Co. Landmark Plant	Algood, AL 35013 Shelby County
Alabama	Longview Lime Co. Saginaw Plant	Woodward, AL 35189 Shelby County
Alabama	Martin-Marietta Cement Roberta Plant	18th Floor Daniel Bldg. Birmingham, AL 35233
Arizona	Amstar Corp. Chandler Plant	50 California St. San Francisco, CA 94106
Arizona	The Flintkote Co. Nelson Plant	1650 S. Alameda St. Los Angeles, CA 90021
Arizona	Kennecott Copper Corp. Ray Plant	Hayden, AZ 85235 Gila County
Arizona	Magma Copper Co. San Manuel Plant	Box M San Manuel, AZ 85631
Arizona	Carley L. More Lime Plant Globe Plant	Box 350 Globe, AZ 85501
Arizona	Paul Lime Plant, Inc. Douglas Plant	Drawer T Douglas, AZ 85607
Arizona	Phelps Dodge Corp. Morenci Plant	Box 187 Morenci, AZ 85540

Location	Company and Plant Name	Address
Arizona	Santa Rita Mining Co. Helvetia Plant	Box 50464 Tucson, AZ 85703
Arkansas	Aluminum Co. of America Bauxite Plant	1501 Alcoa Bldg. 700-2-AC Pittsburgh, PA 15219
Arkansas	Rangaire Corp. Batesville Plant	Box 1311 Batesville, AR 72501
Arkansas	Reynolds Metals Co. Hurricane Creek Plant	6603 West Broad St. Richmond, VA 23226
California	American Crystal Sugar Co. Clarksburg Plant	Box 419 Denver, CO 80201
California	Amstar Corp. Spreckels Plant	50 California St. San Francisco, CA 94106
California	Amstar Corp. Woodland Plant	50 California St. San Francisco, CA 94106
California	Diamond Srpings Lime Co. Diamond Springs Plant	Box 407 Diamond Springs, CA 95619
California	The Flintkote Co. Richmond Plant	1650 S. Alameda St. Los Angeles, CA 90021
California	The Flintkote Co. City if Industry Plant	1650 S. Alameda St. Los Angeles, CA 90021
California	Holly Sugar Corp. Hamilton City Plant	Box 1052 Colorado Springs, CO 80901
California	Holly Sugar Corp. Carlton Plant	Box 1052 Colorado Springs, CO 80901
California	Holly Sugar Corp. Dyer Plant	Box 1052 Colorado Springs, CO 80901

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Location	Company and Plant Name	Address
California	Holly Sugar Corp. Tracy Plant	Box 1052 Colorado Springs, CO 80901
California	Kaiser Aluminum & Chemicals Corp. Natividad Plant	Moss Landing, CA 95039 Monterey County
California	Merck Chemical Co. Sonora Plant	500 E. Grand Ave. S. San Francisco, CA 94080
California	Pfizer, Inc. Cushenbury Plant	Box 558 Lucerne Valley, CA 92356
California	Stauffer Chemical Co. West End Plant	636 California St. San Francisco, CA 94119
California	Union Sugar Co. Betteravia Plant	100 Pine St. San Francisco, CA 94111
Colorado	American Crystal Sugar Co. Rocky Ford Plant	Box 419 Denver, CO 80201
Colorado	CF&I Steel Corp. Pueblo Plant	Box 316 Pueblo, CO 81002
Colorado	Great Western Sugar Co. Brighton Plant	Box 5308, Terminal Annex Denver, CO 80215
Colorado	Great Western Sugar Co. Longmont Plant	Box 5308, Terminal Annex Denver, CO 80215
Colorado	Great Western Sugar Co. Sterling Plant	Box 5208, Terminal Annex Denver, CO 80215
Colorado	Great Western Sugar Co. Loveland Plant	Box 5208, Terminal Annex Denver, CO 80215
Colorado	Great Western Sugar Co. Fort Morgan Plant	Box 5208, Terminal Annex Denver, CO 80215

Location	Company and Plant Name	Address
Colorado	Great Western Sugar Co. Ovid Plant	Box 5308, Terminal Annex Denver, CO 80215
Colorado	Great Western Sugar Co. Eaton Plant	Box 5308, Terminal Annex Denver, CO 80215
Colorado	Great Western Sugar Co. Greeley Plant	Box 5308, Terminal Annex Denver, CO 80215
Colorado	Holly Sugar Corp. Delta Plant	Box 1052 Colorado Springs, CO 80901
Connecticut	Pfizer, Inc. Litchfield Plant	Daisy Hill Road Canaan, CT 06018
Florida	Basic Magnesia, Inc. Port St. Joe Plant	Box 160 Port St. Joe, FL 32456
Florida	Chemical Lime, Inc. Brooksville Plant	Box 250 Ocala, FL 32670
Florida	Dixie Lime & Stone Co. Sumterville Plant	Box 910 Ocala, FL 32670
Hawaii	GasprO, Ltd. Waianae Plant	Box 2454 Honolulu, HA 96804
Hawaii	Hawaiian Commercial & Sugar Co., Ltd. Paia Plant	Box 266 Puunene, HA 96784
Idaho	Amalgamated Sugar Co. Nampa Plant	Box 1520 Ogden, UT 84402
Idaho	Amalgamated Sugar Co. Mini-Cassia Plant	Box 1520 Ogden, UT 84402
Idaho	Amalgamated Sugar Co. Twin Falls Plant	Box 1520 Ogden, UT 84402

Location	Company and Plant Name	Address
New York	Allied Chemical Corp. Syracuse Plant	Box 1219R Morristown, NJ 07960
New York	Bethlehem Steel Corp. Lackawanna Plant	701 E. Third St. Bethlehem, PA 18016
New York	Union Carbide Corp. Niagara Falls Plant	Box 66 Niagara Falls, NY 14302
North Dakota	American Crystal Sugar Co. Drayton Plant	Box 419 Denver, CO 80201
Ohio	J. E. Baker Co. Millersville Plant	Box 1189 York, PA 17405
Ohio	Basic, Inc. Maple Grove Plant	845 Hanna Bldg. Cleveland, OH 44115
Ohio	Cuyahoga Lime Co. Cleveland Plant	Menlo Park Edison, NJ 08817
Ohio	Diamond Shamrock Chemical Co. Painesville Plant	300 Union Commerce Bldg. Cleveland, OH 44115
Ohio	Huron Lime Co. Huron Plant	Box 428 Huron, OH 44839
Ohio	Martin-Marietta Chemicals Woodville Plant	2200 1st National Bank Bldg. Baltimore, MD 21203
Ohio	National Gypsum Co. Gibsonburg Plant	325 Delaware Ave. Buffalo, NY 14202
Ohio	National Lime & Stone Co. Carey Plant	1st National Bank Bldg. Findlay, OH 45840
Ohio	Northern Ohio Sugar Co. Findlay Plant	Box 5308 Denver, CO 80215

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Location	Company and Plant Name	Address
Wisconsin	Western Lime & Cement Co. Green Bay Plant	Box 2076 Milwaukee, WI 53201
Wisconsin	Western Lime & Cement Co. Knowles Plant	Box 2076 Milwaukee, WI 53201
Wisconsin	Western Lime & Cement Co. Eden Plant	Box 2076 Milwaukee, WI 53201
Wyoming	Great Western Sugar Co. Lovell Plant	Box 5308 Denver, CO 80215
Wyoming	Holly Sugar Co. Torrington Plant	Box 1052 Colorado Springs, CO 80901
Wyoming	Holly Sugar Co. Worland Plant	Box 1052 Colorado Springs, CO 80901

ESTIMATE OF TOTAL COAL USED BY LIME INDUSTRY

BASED ON PRODUCTION OF 21 MILLION TONS (1973 PRODUCTION)

$$(21{,}000{,}000 \text{ TONS LIME})(70\% \text{ IN COAL FIRED KILNS}) = 14{,}700{,}000 \text{ TONS LIME PRODUCED}$$

$$(14{,}700{,}000 \text{ TONS LIME})\left(\frac{1 \text{ TON COAL}}{3.37 \text{ TONS LIME}}\right) = 4{,}362{,}000 \text{ TONS COAL}$$

$$\cong 4.4 \text{ MILLION TONS COAL}$$

ESTIMATE OF N/G USED BY LIME INDUSTRY

$$(21{,}000{,}000 \text{ TONS LIME})(27\% \text{ IN N/G FIRED KILNS}) = 5{,}670{,}000 \text{ TONS LIME PRODUCED}$$

$$(5{,}670{,}000 \text{ TONS})\left(\frac{1 \text{ TON N/G}}{6.4 \text{ TONS LIME}}\right) = 885{,}937 \text{ TONS N/G}$$

ASSUME 886,000 TONS N/G

BASED ON SP. GRAVITY = .590 ; DENSITY = 22.6 ft^3/lb

$$(886{,}000 \text{ TONS})\left(\frac{2000 \text{ lb}}{\text{TON}}\right)\left(22.6 \frac{ft^3}{lb}\right) = 4.005 \times 10^{10}$$

4.0,050,000,000. $\cong$ 40 BILLION ft^3 NATURAL GAS

VULCAN-Cincinnati, Inc.

ENGINEERING CALCULATIONS

FOR JN-688 PAGE ______ DATE 3-74

CUSTOMER ______ UNIT ______ BY J. HUNTER

ESTIMATE OF TOTAL OIL USED BY LIME INDUSTRY

BASED ON #6 OIL w/ HEATING VALUE = 153,000
DENSITY = 8.2 lb/gal

(21,000,000 TONS LIME)(3% IN KILN FIRED BY OIL) = 630,000 TONS LIME

$(630{,}000 \text{ TONS LIME})\left(\frac{1 \text{ TON OIL}}{3.04 \text{ TONS LIME}}\right) = 125{,}000 \text{ TONS OIL}$

$(125{,}000 \text{ TONS OIL})\left(\frac{2000 \text{ lb}}{\text{TON}}\right)\left(\frac{\text{GAL}}{8.2 \text{ lb}}\right) = 30{,}487{,}804 \text{ GAL}$

$\cong$ 30.5 MILLION GALLONS OIL

42 gal / BARREL

30.5/42 = 726,000 BARRELS