DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
George K. Burgess, Director

MANUFACTURE OF LIME

CIRCULAR OF THE BUREAU OF STANDARDS, No. 337

DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
George K. Burgess, Director

CIRCULAR OF THE BUREAU OF STANDARDS, No. 337

MANUFACTURE OF LIME

SUPERSEDING TECHNOLOGIC PAPER No. 16
UNDER SAME TITLE

SEPTEMBER 28, 1927

PRICE, 45 CENTS
Sold only by the Superintendent of Documents, U. S. Government Printing Office
Washington, D. C.

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1927

MANUFACTURE OF LIME[1]

ABSTRACT

This publication is a revised edition of Bureau of Standards' Technologic Paper No. 16, published in 1913. It contains an account of the methods employed in the manufacture of quicklime and hydrated lime at various plants and includes a description of nine plants visited in 1925.

CONTENTS

---

[1] The first edition of this publication, by W. E. Emley, was issued in 1913 as Bureau of Standards' Technologic Paper No. 16. The work has been revised and enlarged by J. M. Porter for the present edition.

I. INTRODUCTION

Difficulty having been experienced in specifying the lime best suited for use for a particular purpose in terms other than those of trade names, it was desired if possible to secure such knowledge relative to the products of the various limekilns of the United States as would indicate either by their source or by investigations of the chemical and physical properties of the resulting products which kind of lime would be most efficient and economical for each particular use.

In spite of the common use of lime, exact information regarding many of its properties in the slaked and unslaked conditions is surprisingly meager. To obtain the proper viewpoint in the study and investigations of this product made necessary by the lack of authentic data, it was felt that a first-hand acquaintance with the manufacture of lime was essential. In this way only could the factors affecting the quality of lime during burning and that of the hydrated product during commercial slaking processes be understood with full appreciation of the practical difficulties.

It was deemed both impracticable and unnecessary to attempt to study the quarrying, mining, and lime-burning processes at a large number of plants, of which there are several hundred in the country.[2] It was, therefore, decided that two or three typical plants should be visited in each separate geologic lime-bearing deposit. Nineteen typical plants, distributed through various portions of the United States, were selected and visited in 1912 and 11 in 1925. A general description of nine of the plants visited in 1925 is given in the appendix to this paper.

The field inquiry was conducted with the purpose of obtaining complete information about the process of lime manufacture; of noting the methods of quarrying, mining, and crushing; of selecting typical samples of the limestone which were forwarded to the laboratory for analysis and study; of observing methods of burning and of sampling the resulting lime; and, finally, of following this through the process of hydrating and of sampling the resulting product.

It is the object of this paper to compare the equipments of the various plants and processes, with special reference to economy of operation and quality of the finished product. The results of some laboratory work have been included in the discussion, in order to throw more light on some of the points. The comparative heat efficiency attained by the use of different methods of creating the draft was deemed of sufficient importance to warrant an investigation. This was carried out by running heat balances at 6 typical

---

[2] According to the report of the division of mineral statistics of the United States Geological Survey for the year 1925 the total lime production in that year amounted to 4,580,823 short tons, valued at $42,609,141. The average value per ton was $9.30, and the number of lime burners reported in operation was 450. Lime production was reported from 42 States and Territories, the value of the output of Ohio ranking first, followed by Pennsylvania, Missouri, Massachusetts, Wisconsin, West Virginia, Alabama, and Virginia.

plants (4 of which are among the 19 first visited), and the results are included in this paper.

Acknowledgment is hereby made to the National Lime Association for its substantial aid in the original work; W. E. Carson, who was president of the association in 1912, and the officers of the companies whose plants were visited deserve special recognition for their active cooperation. The original work was carried out under the supervision of A. V. Bleininger, and many of his ideas have been incorporated in this paper. Thanks are also due Dr. Oliver Bowles, superintendent, Nonmetallic Minerals Station, Bureau of Mines, New Brunswick, N. J., for critically reviewing the revised manuscript and offering many helpful suggestions, especially applicable to the sections on quarrying and mining.

II. GENERAL DISCUSSION

1. QUALITY OF STONE

The art of lime burning dates back to earliest antiquity, and until recently comparatively little improvement has been made in the process. The numerous changes which have been introduced in the past few years may be attributed to economic conditions, which have forced progress in the art along rational lines.

The burning of lime may be defined as the process of converting limestone into lime through the agency of heat. The term "limestone" is used to describe a class of rocks varying in composition from pure calcium carbonate to a mixture of 54.35 per cent calcium carbonate with 45.65 per cent magnesium carbonate.[3] Any gradation between these limits may be found, and all limestones contain more or less impurities. In the same way lime may vary from pure calcium oxide to a mixture of calcium and magnesium oxides in the corresponding proportions. The accompanying impurities may or may not be removed. Consequently, the problem of burning lime is merely one of removing the carbon dioxide from the stone by means of heat. When the stone is raised to a sufficiently high temperature and kept there for a sufficient length of time, the carbonates are dissociated and the carbon dioxide is given off as gas.

The quality of limestone suitable for burning may vary, both chemically and physically, within rather wide limits. The chemical analyses of samples of stone collected are given in Table 1. They were made under the direction of P. H. Bates and F. W. Smither, chemists, of the Bureau of Standards.

---

[3] According to definition by the National Lime Association.

TABLE 1.—*Analyses of limestones*

Company and location	Designation of stone	Silica (SiO_2)	Alumina (Al_2O_3)	Iron (Fe_2O_3)	Calcium carbonate ($CaCO_3$)	Magnesium carbonate ($MgCO_3$)	Moisture	Total
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Rockland & Rockport Lime Co., Rockland, Me.	Soft	1.29	0.15	0.35	95.91	2.27	-------	99.97
	Rockport	2.41	.22	.40	85.18	11.72	-------	99.93
Farnam-Cheshire Lime Co., Cheshire, Mass.	[1]	.44	.08	.20	98.05	1.30	-------	100.07
Connecticut Lime Co., Canaan, Conn.	[1]	.34	.19	.28	58.20	41.16	-------	100.17
New Jersey Lime Co., Hamburg, N. J.	McAfee	.85	.06	.20	96.70	2.04	-------	99.85
	Hamburg	1.21	.41	.45	95.70	2.25	-------	100.02
Chas. Warner Co., Cedar Hollow, Pa.	South quarry:							
	West End	.81	.56	.47	54.68	43.66	-------	100.17
	East End	.91	.09	.30	63.02	35.78	-------	100.10
	North quarry	2.27	.51	.40	53.16	43.89	-------	100.23
	Whiteland	.94	.15	.45	54.09	44.58	-------	100.21
Palmer Lime Co., York, Pa.	White	.53	.04	.05	99.21	.74	-------	100.57
	Blue	.14	.02	.10	98.73	1.01	-------	100.00
	Calico	.27	.07	.30	86.43	12.98	-------	100.05
American Lime & Stone Co., Bellefonte, Pa.	Quarry No. 13	1.41	.25	.40	96.36	1.55	-------	99.97
Thomasville Stone & Lime Co., Thomasville, Pa.	[1]	.15	.10	.15	99.02	.57	-------	99.99
Riverton Lime Co., Riverton, Va.	Slaty	.42	.07	.32	97.20	2.02	-------	100.03
	Oily	.36	.07	.22	96.07	3.26	-------	99.98
	[1]	.46	.06	20	89.20	10.14	-------	100.06
E. Dillon's Sons, Indian Rock, Va.	Upper Quarry	.28	.16	.20	98.50	.78	-------	99.92
	Lower Quarry	.80	.10	.35	97.05	1.72	-------	100.02
	Fertilizer	1.05	.40	.55	96.21	1.76	-------	99.97
Tennessee Marble Lime Co., Knoxville, Tenn.	Main quarry	.16	.13	.06	98.93	.76	-------	100.04
	Other quarry	.23	.08	.20	98.25	1.26	-------	100.02
	Luttrell	.65	.05	.30	84.50	14.53	-------	100.03
Lagarde Lime & Stone Co., Lagarde, Ala.	[1]	1.64	.33	.31	94.39	3.42	-------	100.09
Ash Grove Lime & Cement Co., Ash Grove, Mo.	[1]	.10	---------	.05	99.05	.88	-------	100.08
Glencoe Lime & Cement Co., Glencoe, Mo.	Gray	.32	.13	.30	98.29	1.05	-------	100.09
	Blue	.21	.06	.15	98.89	.67	-------	99.98
	Brown	.26	.02	.20	98.84	.65	-------	99.97
	White [2]	1.35	.53	.40	94.89	3.05	-------	100.22
Marblehead Lime Co., Marblehead, Ill.	[1]	.21	.04	.10	98.45	1.28	-------	100.08
Sheboygan Lime Works, Sheboygan, Wis.	[1]	.55	.24	.40	55.09	43.91	-------	100.19
Union Lime Co., High Cliff, Wis.	[1]	1.12	.06	.40	54.82	43.79	-------	100.19
White Marble Lime Co., Manistique, Mich.	Manistique [2]	1.92	.03	.30	54.04	43.81	-------	100.10
	Blaney	1.23	.19	.50	94.38	3.74	-------	100.04
	Marble	.56	.05	.20	55.00	44.31	-------	100.12
	Indian	1.04	.05	.25	54.25	44.52	-------	100.51
Woodville White Lime Co., Woodville, Ohio.	[1]	.34	.02	.15	56.79	42.92	-------	100.22
Louisville Cement Co., Milltown, Ind.	[1]	.46	.09	.05	99.20	.25	0.07	100.12
Glencoe Lime & Cement Co., Glen Park, Mo.	[1]	.24	.14	.02	98.30	Trace.	.15	98.85
Peerless White Lime Co., Ste. Genevieve, Mo.	White	.20	.01	.03	99.40	.40	.02	100.06
	Gray	1.60	.02	.08	95.00	3.30	.03	100.03
Allwood Lime Co., Manitowoc, Wis.	Baby milk 1	.78	.13	.05	54.80	45.00	.16	100.92
	Milk 2	.38	.19	.07	54.50	45.00	.04	100.18
	Vienna	.14	.21	.05	54.80	45.00	.05	100.25
	Horologic	.16	.18	.04	55.40	45.30	-------	101.08
	Lump	.80	.11	.09	55.00	44.75	.05	100.80
Ohio Hydrate & Supply Co., Woodville, Ohio.	[1]	.34	.02	.15	56.79	42.92	-------	100.22
Kelly Island Lime & Transport Co., Marblehead, Ohio.	[1]	1.75	.36	.11	87.70	10.10	-------	100.02

[1] Average of stone burned for lime.

[2] Not burned for lime.

The chemical composition of a lime depends on that of the stone from which it was made. Consequently, only those limestones may be used from which a marketable lime can be produced. It must be remembered that on account of the loss of about half the weight of the stone as carbon dioxide during the burning the proportion of every other constituent of the stone will be nearly doubled in the lime. The composition which lime should have for particular purposes has been studied recently by such bodies as the Interdepartmental Conference on Chemical Lime and the Lime Committee of the American Society for Testing Materials. The amount of impurities (silica and oxides of iron and aluminum) permissible in a finishing lime (quicklime or hydrate) is very small, certainly not over 5 per cent (2½ per cent in the stone). The proportion of iron especially should be very low because of its tendency to color the lime red or yellow. The value of lime in chemical industries depends in large measure on the amount of the active constituent. Therefore the impurities act usually as diluents, and for many purposes their presence in rather large amounts is not harmful. However, in some processes, such as in the manufacture of leather, sugar, glass, silica, and sand-lime brick, the presence of impurities is objectionable because of reasons other than that they are diluents.[4] For building purposes small amounts of impurities are not objectionable and may, in some instances, improve the quality of the finished product. This bureau has studied the effects of various impurities on the properties of lime, and believes the following general conclusions may be drawn: The presence of small amounts of silica tends to decrease the plasticity, sand-carrying capacity, and yield of a lime, but has no apparent effect on its hardness or strength. The same may be said of iron, except that lime containing large amounts (25 per cent) shows a marked increase in both strength and hardness. Alumina increases all of the factors above mentioned and also improves the color so that its presence, even in large amounts, is very desirable. On the contrary, gypsum shows detrimental effects, even when only 1 per cent is present. Kaolin seems to act in a manner similar to silica and iron.

Because of its greater plasticity the majority of consumers prefer a magnesian hydrated lime to a high calcium lime for finishing purposes. These conditions are reversed in the demand for building lime. In the chemical industries the proportions of calcium and magnesium depend entirely on the particular use of the lime, but most industries demand a high calcium product.

Calcium and magnesium oxides play important but distinct parts as fertilizers. The amount of either permissible in a lime to be used for this purpose depends on the condition of the soil and the kind of crop, and must be varied to suit each particular case.

---

[4] See Section VI.

Thus it is seen that the presence of a rather large amount of impurities in the stone is permissible, except where a finishing lime or a particular grade of a chemical lime is to be made. The ratio of calcium to magnesium desired depends largely on the market in the particular locality. When the lime is sold for chemical purposes this ratio will generally be specified.

The chemical composition of the stone influences the cost of burning. Experience has shown that it generally requires less heat and a lower temperature to burn a magnesium than a high calcium stone. The greater the proportion of impurities, the more easily is the lime overburned, and therefore too large an amount of these constituents will cause a diminution of the capacity of the kiln. It is possible that the proportion of silica may be high enough to form the dicalcium silicate ($2CaO.SiO_2$). This substance when cooled slowly assumes allotropic forms. Thus at 675° C. (1,247° F.) it changes from the β to the γ modification, with a marked increase in volume.[5] This causes the lime to fall to pieces, a phenomenon commonly known as "fire slaking."

From the chemical analyses of the samples of stone collected it will be seen that the amount of lime varies from 29.77 to 55.56 per cent, and of magnesia from 0.31 to 21.23 per cent, but that the total quantity of combined carbonates in any stone is never much less than 97 per cent. The silica is occasionally somewhat over 2 per cent without injury to the stone for lime burning, but the alumina and oxide of iron are generally under one-half of 1 per cent. It must be remembered, however, that this investigation did not cover the entire field, and there are limes being produced in which the proportion of impurities is so high that they are practically cements.

So far as its physical properties are concerned, any kind of limestone is suitable for burning. These properties do, however, influence the cost of production to a noticeable extent. Experience has shown that fine-grained, dense stone can be burned at a lower temperature and with less heat than one which is coarsely crystalline and porous, no doubt because the former is a much better heat conductor than the latter. Coarsely crystalline stones, especially if very pure, are apt to fall to pieces in the kiln, thus reducing the production of lump lime. The same occurrence is sometimes noticed when a porous stone is used, although in this case it is probably due to the rapid expulsion of water from the pores. On the other hand, laboratory work done by this bureau indicates that "all naturally porous stones lost their carbon dioxide at a lower temperature, 900° C. (1,652° F.), than the denser materials."[6]

---

[5] A. L. Day and E. S. Shepherd, "The lime-silica series of minerals," J. Am. Chem. Soc., p. 1089; 1906.

[6] Bleininger and Emley, "Burning temperature of limestone," Trans. Nat. Lime Assoc., p. 77; 1911.

Whether a limestone is porous or not, its water content is of importance, for this water must be evaporated, with the consequent loss of heat and lowering of kiln efficiency. Moreover, some of the water, in chemical combination with the clayey impurities of the stone, will probably not be given off until the stone has reached a red heat. This will require the stone to remain in the burning zone for a longer time, and may, therefore, reduce the kiln capacity to some extent.

2. BURNING

There are three factors essential to the process of lime burning: (1) The stone must be heated to the temperature of dissociation of the carbonates; (2) this temperature must be maintained for a certain length of time; (3) the carbon dioxide evolved must be removed.

Many experiments have been made to determine the temperature of dissociation of calcium carbonate. The best and most recent work done on this subject has been by Johnston[7] and Mitchell.[8] Both of these investigators found the dissociation temperature to be 898° C. (1,648° F.). The corresponding temperature for magnesium carbonate has not been determined as accurately and the results are not at all concordant, but the value 756° C. (1,393° F.) obtained by Mitchell[8] in 1923 is probably quite correct. These figures are for a pressure of 1 atmosphere of carbon dioxide, a condition hardly ever met with in practice. The dissociation temperature of stones containing magnesium carbonate depends upon the manner of combination of the two carbonates. Some investigators have found the two materials to behave as separate compounds, dissociating at their respective temperatures. On the other hand, others have found the behavior to indicate the presence of a double salt, with the dissociation temperature lying between that of calcium carbonate and magnesium carbonate. Recent work conducted at this bureau[9] indicated the latter condition to be true.

After the dissociation temperature has been reached it must be maintained for some time in order to transfer the required amount of heat to the stone. Johnston, quoting from Thomsen,[10] gives the heat of dissociation of calcium carbonate as 42,900 calories per gram molecule at 27° C. (81° F.). Assuming a rate of variation of this factor with the temperature, he calculates the figure to be 38,500 calories at 827° C. (1,521° F.). Since the heat of dissociation of calcium carbonate at the temperature ordinarily used in practice has never been determined, it can not be stated that the figures given are scientifically accurate, and the same inaccuracy of our

---

[7] Johnston, "Thermal dissociation of $CaCO_3$," J. Amer. Chem. Soc., **32**, p. 938; 1910.

[8] Mitchell, J. Chem. Soc., **123**, p. 1055; 1923.

[9] D. F. Richardson, "Analysis of hydrated lime by a thermochemical method," J. Ind. and Eng. Chem., **19**, p. 625; 1927.

[10] Thomsen, Thermochemistry, Longmans, Green & Co., London; 1908.

knowledge is true with magnesium carbonate. In the discussion of the heat efficiency of lime kilns, we have assumed these figures to be 693.6 B. t. u. per pound for calcium carbonate and 520.6 B. t. u. per pound for magnesium carbonate, admitting that these figures are not accurate, but claiming in their defense that they are probably sufficiently near the truth for practical purposes.

The physical properties of the stone undoubtedly have some influence on the amount of heat required and the time in which this heat can be transferred at any given temperature. Thus, it will take longer to burn a large piece of stone than a smaller one. A fine-grained, dense stone will conduct the heat more readily than one which is coarsely crystalline and porous. Practical experience seems to point to the fact that the crystals themselves require more heat to dissociate them than the more fine-grained stone. The time required to transfer a given amount of heat, roughly speaking, varies inversely with the temperature difference. Therefore, it has been found economical to use as high a temperature as possible in order to reduce the time required for burning. The upper limit of the temperature is determined by the phenomenon of "overburning." Overburned lime can be recognized by its yellow color and the extreme length of time it takes to slake, together with the fact that it is appreciably heavier than the white, properly burned lime. These properties are probably caused by the chemical combination of the lime with the impurities (especially with the silica and silicates) contained in it and the reduction in the percentage of pore space in the quicklime. Lime may be overburned by being heated for too long a time as well as at too high a temperature. In general, it is better to underburn than overburn the lime, for the unburned stone may be put back into the kiln while the overburned lime is useless. Moreover, the properties of overburning seem to assert themselves gradually, so that the best lime is obtained by using the minimum amount of heat.

To summarize, a certain quantity of heat must be supplied to dissociate the carbonates in the stone. The quantity varies with the chemical and physical properties of the stone. In supplying this heat it is optional to use either a high temperature for a short time or a lower temperature for a longer time. Since the dissociation pressure of calcium carbonate is a logarithmic function of the temperature, a slight increase of temperature will cause a decided increase in the dissociation pressure, and a correspondingly large reduction in the time required to produce a given quantity of lime. If magnesium carbonate is present in appreciable quantities a lower temperature should be employed. The more nearly the amount of heat used approaches the minimum required the better will be the quality of the lime.

It is well known that the chemical reaction involved in burning lime is reversible; that is, calcium carbonate may be decomposed into calcium oxide and carbon dioxide, or these substances may recombine to form calcium carbonate. The factor which determines the way the reaction shall go is the pressure of carbon dioxide.[11] If this gas is removed as formed so that its partial pressure is kept below that given for the temperature by Johnson's or Mitchell's equations, the reaction will continue in the direction to form lime, but if the gas is allowed to accumulate until its pressure becomes higher than this, the reaction will be reversed and will give rise to the phenomenon known technically as "recarbonating." Therefore, rapid and continuous removal of the gas is essential in lime burning.

3. CHEMICAL AND PHYSICAL PROPERTIES OF LIME

Lime, chemically speaking, is the oxide of calcium, but the commercial article may differ widely from this composition. It may contain anywhere from 0 to 44 per cent of magnesium oxide and generally contains more or less impurities, such as silica and oxides of iron and aluminum. When properly burned and fresh from the kiln, it should contain no water and less than one-half of 1 per cent of carbon dioxide. If the impurities added by the combination between the lime and the kiln lining be neglected, the composition of any lime will be the same as that of the stone from which it was burned, minus the carbon dioxide.

The lime will generally retain the same form as the stone, but the porosity is increased very greatly. The color of lime is nearly white, but may have a gray, pink, or yellow tinge, depending upon the impurities present. Stones in which crystals are apparent frequently retain the same structure after calcination.

When lime is slaked the calcium oxide combines with water to form calcium hydroxide. The impurities may be present in chemical combination with the calcium oxide in which event they also may take up some water. The hydration of the magnesium oxide in a magnesium lime has always been thought to be nearly negligible, but some recent work at this bureau,[12] indicates that from 40 to 70 per cent of the magnesium oxide present does hydrate in the commercial process.

The hydration of calcium oxide generates heat. Since a part of the magnesium oxide does not hydrate, this portion acts merely as an inert substance which must be heated by the calcium oxide. Therefore, other things being equal, the less magnesium oxide present in a lime the more quickly it will slake and the greater will be the amount of heat generated.

---

[11] Bleininger, Trans. Amer. Cer. Soc., 9, p. 454; 1907.

[12] See footnote 9, p. —.

The porosity of the lime plays a very important part here, however. Thus, the more porous the lime the more quickly can the water penetrate it, and hence the chemical combination will take place more readily. Indeed, in some cases the porosity seems to be of more importance than the chemical composition; that is, a very porous dolomitic lime may slake more quickly than a dense lime, with a much higher content of calcium oxide.

If lime is underburned the calcium carbonate left in it acts as inert matter. Overburned lime exhibits the same phenomenon, although in this case it is probably due to a diminution of the pore space and the quantity of active calcium oxide present. At the higher temperatures the calcium oxide combines with the impurities, and hence is not free to take part in the reaction of slaking.

The appearance of underburned lime varies with that of the stone, and can be distinguished only by one who has had practice with the particular lime in question. Overburned lime is generally yellow or black in color and can be readily separated from good lime.

When lime is exposed to the air it absorbs carbon dioxide and water and "air slakes." This reaction takes place in two more or less distinct stages, first, the absorption of water and, second, the displacement of the water by carbon dioxide. Since these reactions are slow, it is possible to obtain lime which has air slaked to almost any degree, and this has led to a great confusion in the literature in regard to the properties of air-slaked lime. For instance, at one stage of the process (when the water has been absorbed and has not been displaced to any extent) the product is similar in composition to "water-slaked" or hydrated lime. In order to avoid such confusion, this bureau has decided to designate as air-slaked lime only that product in which the process has been completed; that is, air-slaked lime is chemically similar to limestone. Any intermediate product will be designated as partially air slaked.

The absorption of water during the process of air-slaking involves a large increase in volume, and therefore the lumps fall to pieces. This fact was an obstacle in the introduction of hydrated lime because the consumer believed that all fine lime was air-slaked. There are several grades of limestone which fall to pieces in the kiln. The stone may be so soft that it is broken up by abrasion; it may have its pores filled with water, which when heated shatters the stone; or its component crystals may be bound together by organic matter which is consumed in the kiln. Stones like these are being burned, and in some cases over 50 per cent of the output of the kiln is fine stuff. Such fine lime is as good for all purposes as lump lime, and it is easier to handle and will keep better. This is obvious from the consideration that the top layer of a pile of fine lime will air-slake and the crust of inert material so formed will prevent access of the air to the quicklime underneath.

The weight of a lump of lime is about 55 per cent of the weight of the stone from which it was burned. Owing to the fact that the lime is in lumps and the weight which any given volume will contain varies considerably, statutes have been enacted by many States legalizing the weight of a given volume. Furthermore, the Federal lime barrel law makes a large or small barrel of lime 280 or 180 pounds net, respectively. The writers have adopted the short ton as the unit to be used when comparing kiln capacities.

4. HYDRATED LIME

Hydrated lime is a product of comparatively recent origin. As its name indicates, it is lime which has already been hydrated; that is, the chemical combination with water has already taken place. It is a fine, dry, white powder which is shipped in paper bags, and which may be used for a number of purposes instead of lump lime.

The keeping qualities of hydrated lime have been the subject of a great deal of discussion. The original statement which was generally accepted was that hydrated lime would keep indefinitely. Going on this assumption, samples were tested in their ordinary commercial packages. The average of 11 samples so received showed a content of 3.77 per cent carbon dioxide, and 1 of them contained 10.09 per cent. These figures correspond, respectively, to 8.57 and 22.93 per cent of calcium carbonate or inert material which had presumably been introduced by air-slaking in transit. In order to investigate this matter a sample of lime was ground, mixed thoroughly, and screened through a 60-mesh sieve. It was then divided into two parts, one of which was slaked with an excess of water, dried in an atmosphere free from carbon dioxide, ground and screened through a 60-mesh sieve. The two samples (one of quicklime and one of hydrated lime, prepared from the same material and having the same fineness) were exposed to the action of the air under the same conditions and were analyzed for carbon dioxide at frequent intervals. The results are as follows:

Age of sample (days)	Percentage of carbon dioxide	
	Quicklime	Hydrated lime
1	0.93	3.14
4	1.68	6.38
6	3.23	7.45
7	3.87	10.34
8	4.02	10.73
10	8.73	11.25

These figures seem to prove that hydrated lime will not keep any better than quicklime of the same fineness. The fineness is important, however, for the same reason which was cited in the case of lump lime versus ground lime—an impervious coating of air-slaked lime will form on the top of a pile of hydrated lime and prevent access of the air to the interior of the pile.

The chief advantages to the consumer of hydrated lime are as follows: It can be handled more easily on account of its being in powder form; it will keep better than lump lime for the reasons just noted; it does not require slaking, but must merely be soaked in water to prepare it for use. This saves time and labor and eliminates any danger of loss of lime due to unskilled slaking. Any unburned lime or overburned lime which has passed the sorter will not hydrate and can be screened out of the finished product. Hence, hydrated lime should contain less refuse than lump lime. On the other hand, hydrated lime contains 15 to 25 per cent of water, on which the consumer must pay the freight.

Manufacturers reap several advantages from the operation of a hydrate mill. It gives them a product which can be stored, so that in no case need the kiln be shut down because of a slack period. There are several grades of stone utilized which burn either to a dark-colored lime or one which falls to pieces in the kiln. Such lime can not be marketed as lump lime, but will give a good quality of hydrate.

A very convenient method for testing hydrated lime is to determine its content of carbon dioxide. If properly made and stored, the amount of carbon dioxide should be less than 1 per cent. Another method which might prove of value as a comparative test depends upon the density of the material. Pure calcium hydrate has a lower specific gravity than any other material which may be present in hydrated lime except water. Of 19 samples of commercial hydrated lime tested by this bureau 8 samples of high calcium hydrate showed densities between 2.15 and 2.24; 7 samples of dolomitic hydrates showed densities greater than 2.38; the other 4 samples showed densities between 2.34 and 2.38. Two of these were high calcium hydrates containing unusually large amounts of silica, one was a high calcium hydrate with a large amount of unhydrated lime (quicklime), and the fourth was a dolomitic hydrate in which more than the usual amount of magnesia was hydrated. A rapid method for determining the relative plasticity of a lime is that developed by Carson[13] which consists of the spreading of a soaked paste on an absorptive base, such as blotting paper. This test in the hands of one experienced with its operation is exceedingly accurate. However, for results which can be expressed and checked by others the Emley plasticimeter[14] should be employed.

---

[13] Emley, W. E., Proc. Nat. Lime Assoc., p. 175; 1916.

[14] American Society for Testing Materials, Std. Spec. for Hydrated Lime for Structural Purposes (C6-24).

III. PROCESS AND ECONOMY OF MANUFACTURE OF QUICKLIME

In discussing the process and economy of manufacture the apparatus and methods observed at various plants will be compared with a view of ascertaining, first, the influence of each method on the economy of operation and the quantity and quality of product, and second, the most suitable apparatus for each particular step in the process.

The discussion will cover in detail the quarries, mines, kilns, and combustion of fuels, with reference to the character of the product.

1. QUARRIES [15]

On account of the extreme variations of limestone deposits it is impossible to formulate any definite rules for quarrying which will apply to all of them. However, a few generalities may be stated.

Thus it is usually true that the quality of the stone throughout the same bed (within a small area) will be more nearly uniform than that from different beds. It is therefore advisable when opening a quarry to follow either the dip or the strike of the beds rather than to cut across them.

If a quarry can be so located that its floor is above the tops of the kilns the cost of hoisting stone can be eliminated. Where this is not possible, it would seem best to maintain the floor at about drainage level. From a given area this will render available the maximum quantity of stone which can be obtained without pumping. In some cases the value of real estate is sufficiently high to warrant quarrying stone below drainage level, even though a considerable quantity of water must be pumped. An economical method of handling the water is to drain it into a "water hole" or "sump" and raise it to the surface by means of an electric or steam pump.

Experience indicates that the cost of labor and explosives will be less if the quarry can be worked with a vertical rather than an inclined face and that a vertical face about 20 feet high can be worked to best advantage. However, a face up to 50 feet or even higher can be worked successfully by churn drill methods.

(a) OVERBURDEN

Overburden is the name technically applied by quarrymen to the material which covers a deposit of stone. It may consist of almost any kind of material, but the substances generally met with in the lime industry are clay, gravel, and impure or weathered limestone. The clay or gravel may be of commercial value, and the impure or weathered limestone is generally marketable as ballast or for road

---

[15] For a more comprehensive discussion of the quarrying of limestone see Bureau of Mines Bulletin No. 269, Quarry Problems in the Lime Industry.

Fig. 1.—*Quarry of the Palmer Lime and Cement Co., York, Pa.*

material. However, stone to be used for lime manufacture should be quarried where the overburden is as little as possible. The impure limestone, and more especially the clay, is apt to be mixed with the stone for burning and may impair the quality of the lime.

If the beds of stone are nearly horizontal and are covered by clay or gravel of uniform thickness, the removal of the overburden (stripping) may be done by hand, digging and hauling in carts, by the use of the plow and scraper, or by means of the steam shovel, depending on the thickness of the overburden. If the beds are horizontal but the country is hilly, it is evident that the thickness of the overburden will vary with the height of the hill. Clay from such a formation can be washed away by hydraulic pressure where a sufficient volume of water is available and drainage is possible. Sometimes, however, it ceases to be economical, and underground mining of the limestone must be practiced.

In some localities the beds of stone have been steeply tilted and the outcrop either broken off or eroded. The overburden in such a formation is apt to occur in pockets, which may extend down to some distance between the beds. Wherever there are many pockets of considerable size a steam shovel may be employed to advantage, but if the pockets are small, hand methods will have to be resorted to.

(b) DRILLING

After the overburden has been removed holes are drilled in the stone preparatory to blasting. This is generally accomplished by means of a common bar drill, operated by steam, compressed air, or electricity; or by churn drills. At 17 of the 24 plants visited the holes are drilled vertically. At 3 of the others both vertical and horizontal holes are used, and at the plants where the stone is mined horizontal holes were employed in driving headings; vertical holes were drilled in the following benches. The holes are from 1½ to 2 inches in diameter and from 10 to 26 feet deep, depending upon the available depth of stone. Vertical holes are drilled in a row from 4 to 8 feet back of the working face of the quarry and from 5 to 15 feet apart. The distance between holes is governed by the hardness and bedding of the stone and by the fineness to which it is desired to shatter it.

Of the quarries visited the drilling is done in 15 by compressed air, in 2 by electricity, and in 7 by steam.

Compressed air is very well suited for this purpose. The air compressor may be installed in the central power plant, since there is very little loss during the transmission to the drills. The air may be carried by a 4 or 6 inch pipe from which it can be distributed to the drills by 1-inch leads. It is generally compressed to from 50 to 100 pounds pressure, the most usual pressure being 90. Objection has been raised to the use of air drills because such a small amount of the energy put into an air compressor is available for useful work at the drills, but this is more than balanced by the low upkeep costs and dependability in comparison with other types of drills.

Electricity has many economical advantages over compressed air, but its use has been limited because of the unreliability of such drills. However, the loss in transmission is low; the current may be used for other purposes besides drilling and time will be saved, because in moving a drill from place to place it is necessary merely to connect another length of wire. Furthermore, when a blast is made, pipes for steam or air drills are apt to be covered up or damaged while wires can easily be moved out of the way.

On the other hand, steam would seem to be the least economical power for drills. If the quarry is at a distance from the kilns steam can not be generated economically in a central power plant on account of the high cost of transmission; therefore, a boiler for this especial purpose must be maintained at the quarry or mine. This entails extra labor and handling of fuel and even then the loss of power in the pipes leading to the drills is apt to be very large.

(c) BLASTING

It is practice in quarrying or mining stone for lime burning to blast it loose. Blasting also serves the purpose of breaking the stone to pieces small enough to be put into vertical kilns. There are two methods of blasting in common use; by one method the stone is merely loosened and thrown down into the quarry or mine in large pieces; by the other it is shattered to pieces small enough for immediate use. The difference in operating by these methods is in the number and position of the holes and the kind of explosive used; the more finely the stone is to be shattered the closer must the holes be to each other and to the working face, and the more powerful must be the explosive.

The former method requires less explosive for the first blast, but the large stones thrown down must be drilled and blasted separately, so that this method probably requires in the end more labor and explosive than the second. On the other hand, the second method produces a much larger proportion of fine material. This is a serious objection, particularly when no crushed limestone is produced.

The selection of the explosive to be used depends on the nature of the stone and the method of blasting desired. For a very soft stone, or if the stone breaks out in large pieces, a large amount of weak explosive, such as black powder, would answer the purpose. If the stone is hard, or if it is desired to shatter it, 35 or 40 per cent dynamite is the explosive in general use.

It is often the practice to "spring" the holes, before blasting. This is done by charging them with dynamite, using a succession of charges of increasing size, but not in sufficient amount to loosen the rock. When this is set off it springs or enlarges the ends of the holes into chambers, thus giving room for a larger charge of explosive for the regular blast. Since more explosive may be used in each hole, it follows that a smaller number of holes are required to blast out a given mass of rock; that is, the method of springing the holes saves drilling, but costs more for explosives. It is therefore probably more economical for hard rock but less so for soft rock.

(d) SORTING AND LOADING

After the stone has been blasted loose and thrown down into the quarry or mine the larger blocks are broken up with dynamite. This is generally placed in holes drilled in the blocks, but may simply be laid on the top of the stone and covered with mud. The former method is called "pop shooting" and the latter "mud capping." Pop shooting requires more labor and power than mud capping, but saves so much in the cost of dynamite that the latter method has been abandoned except in cases where steam drills are used.

The stone is then broken still smaller by sledging until it is reduced to the size necessary for charging into the kilns. It is then loaded into the car, cart, or wheelbarrow, which takes it out of the mine or quarry. This loading is generally done by hand in mines and many quarries so as to give an opportunity for sorting of the stone. For this loading operation steam and electric shovels have recently come into quite extensive use.

Limestone must be sorted in order that only the proper quality and size of stone may be put into the kiln. In cases where rotary kilns are used this latter phase is taken care of by crushers, a subject which will be discussed fully in another section. The quality of stone required for burning has already been described. If the stone is quarried, the quarry should be so located and operated as to give as little unsuitable stone as possible. If some "bad" stone must be worked with the good, its appearance should form a clear indication of its character, otherwise it can not be sorted out, and lime of poor quality may result. If the lime is to be used for finishing purposes, particular attention must be paid to sorting the stone, since any great amount of clay adhering to the surface of an otherwise good stone is apt to cause pitting after application to the wall.

With vertical kilns the size of stone to be used depends on two considerations: A hard dense stone may be used in smaller sizes than one which is soft and has a tendency to fall to pieces in the kiln. If the draft is normally rather low, large stone should be used, or the draft may be choked below its economical limit. It is the general custom to use anything from a "one-man" stone (a stone as large as one man can readily handle) down to about 4 inches in diameter. On account of more nearly uniform draft it would probably give greater kiln efficiency if the stone were sorted more nearly to the size required by the kiln, but this is hardly economical unless a good market for crushed stone is at hand, so that good use may be made of the smaller sizes.

(e) TRANSPORTATION

Numerous methods are used for taking the stone from the quarry or mine to the kilns or crushing plant. This is to be expected, since the method must be varied to suit the particular conditions of each plant, such as the distance between the quarry or mine and kilns, the shape of the quarry, the elevation from the mine or quarry floor to the crushers or kilns, and the amount of stone to be handled. An enumeration of the methods used includes wheelbarrows, carts drawn by horse, cars drawn by horse, cable, or locomotive, and cars or buckets transported by aerial cables, and skips hoisted by derricks. It is frequently the custom to use two or more of these methods in combination.

The transportation of stone may be considered as being carried out in three stages: (1) Removing the stone from the quarry or mine; (2) carrying it from the quarry or mine to the kilns or crushers; (3) in the case of vertical kilns, elevating it to the top of the kilns.

The wheelbarrow has the advantage over all other vehicles except the cart in that its direction of action is unlimited; that is, it can follow the constantly shifting working face of the quarry or mine. However, taking stone out in a wheelbarrow is a very slow and laborious process and is certainly not to be recommended even when the quantity of stone to be moved is very small. Wheelbarrows are generally out of the question when it comes to transporting the stone to either rotary or shaft kilns, but they are sometimes used for elevating stone to the top of shaft-kilns when the charging doors are too small to admit a whole carload.

The horse and cart has the same unlimited action in the quarry or mine as the wheelbarrow. If the distance to the kilns or crushing plant is not too great, this vehicle may be used for the transportation, and there are instances in shaft kiln operation where the elevation is sufficiently low so that the horse can haul the stone to the top of the kilns. The method is very slow, however, and is not to be recommended where any considerable amount of stone must be moved.

Tramcars labor under the disadvantage of requiring tracks. These tracks must be extended and shifted to keep up with the working face, and they must be moved every time a blast is made. If shaft kilns are used, located very near the quarry or mine, it is the custom to slope the floor of the quarry or mine, so that the cars can be taken to one point by gravity. In this case a cable is hooked on, and they are drawn up an incline to the top of the kilns. If the kilns are over one-half mile from the quarry or mine, it is generally considered economical to use a locomotive for the transportation. If the distance is too short to warrant this but too long for a cable, animal power may be used. Generally it will be found impossible, on account of the grade, for either locomotive or horse to take the stone to the top of the kilns. They deliver it at the foot of an incline, where a cable is attached to pull it up to the top. If the incline is extremely steep, this arrangement is called a "skip hoist."

The consensus of opinion seems to be that the construction and repair costs of aerial cables are higher than for other methods of transportation. Moreover, they are not adaptable to the changing face of the quarry, so that some other means must be relied on to take the stone to them. They may be necessary in some instances, however, as when the stone must be carried over a hill too steep for a locomotive or horse or over a railroad track.

If the quarry is very deep, sometimes the only possible way to get the stone out is by hoisting. It may be loaded on skips and pulled up by derricks, which load it on cars for transportation to the kilns or crushers.

Since the method of transportation must be varied to suit local conditions, it is not surprising that each operation visited was equipped with a different method of handling the stone.

2. MINES [16]

The mining of limestone is a somewhat recent innovation in the industry, and at present the tendency is toward this method of operation for several reasons: (1) Increased difficulties in quarry operation; (2) the demand for a higher quality of lime, necessitating a better and more nearly uniform stone; (3) operating conditions more or less independent of the weather conditions.

When an overburden becomes so heavy as to be uneconomical to remove, or if the deposit of stone in the strike direction (because of property limitations or other reasons) is exhausted, underground methods of mining the rock become imperative. Clay pockets or seams in the upper ledges of a deposit give rise to difficulty in stripping and may also be a reason for abandoning quarrying operations. When mining is employed, clay and other contaminating substances usually encountered in quarry workings are eliminated. This is a matter of vital concern to some limestone users, for the purity of the stone is of advantage, and especially so if all of the stone is burned to lime. In wet weather clay sticks tenaciously to the stone obtained in open quarry work, it is silicious, and the result is apt to be poor quality lime.

---

[16] For a more comprehensive discussion of the mining of limestone, see Bureau of Mines Bulletin No. 262, Underground Limestone Mining.

The most disadvantageous feature of mining limestone is the greatly increased amount of fine stone. This is not such a serious matter if a rotary kiln is employed, as is usually the case with mining operations.

(a) DRILLING

In mining operations the drilling is materially different from that employed at quarries. Smaller drills on low benches are used, necessitating the placing of the holes much closer together. As with quarry operations, the relative distance between holes is governed by hardness and bedding of the stone.

(b) BLASTING

Because of the fact that the drill holes are so much closer together in mine operations as compared with quarried, the blasted stone contains a larger proportion of fine material and less of the rock which has to be further reduced by "pop shooting" or "mud capping." The type explosive employed is the same as that used in quarrying, namely, 35 to 40 per cent dynamite.

(c) SORTING AND LOADING

The discussion relative to sorting and loading given under quarry operation applies also to mining. However, in mining, the fine material is less liable to be contaminated with dirt, clay, etc., and, because of this, it is usual to employ it either for the manufacture of lime or for crushed or ground limestone products.

(d) TRANSPORTATION

The methods used for conveying the stone from the mine face to the kilns are not so varied as in the case of quarrying. In fact, there were only two methods observed—cars drawn by horses or mules and cars drawn by electric locomotives. Mine hoists are sometimes employed. Animals and cars are used when the distance to be hauled is not very great. They are also employed to assemble the cars into trains in the mine, the locomotives taking the trains so assembled from the mine to the kilns. When the distance from the mine face to the kilns is less than one-fourth mile horses or mules may be economically employed to haul the stone. For distances greater than this their use is not economical.

The type of car depends to a great extent upon the manner of charging the kilns. In general, two are used—side or bottom dump, and the "removable container" type. The former are used when the cars dump directly into the kilns or crusher and the latter when a boom elevates the stone and discharges it into the kilns.

The bottom-dump and side-dump types of cars are usually built of iron and hold 2 or 3 tons of stone. In the bottom-dump type the bottom consists of two plates so hinged that when released they will swing downward and allow the stone to fall into the kiln or crusher. Side-dump cars are built V-shaped in cross section, so that they are top heavy when full of stone and must be fastened to the trucks on both sides. When dumping, the fastening on one side is released and the car permitted to roll over toward the other side. It must be righted again by hand. An interesting device in this connection is the automatic car. The fastening of this is tripped by an upright piece bolted to the track, the car rolls over and discharges its load, and is righted again by springs attached to the trucks.

When the "removable-box" type cars are employed they are run up either to the side or to the front of the kilns where a boom or hoist lifts the boxes, by means of attached rings, to the top of the kilns. This type car is not employed in connection with rotary kilns.

3. METHOD AND TIME OF CHARGING KILNS

(a) VERTICAL KILNS

When stone is brought to the kilns by horse and cart the method of dumping it in needs no explanation.

The descriptions which have been given of the side-dump, bottom-dump, and "removable-container" types of cars indicate the methods employed in the charging of vertical kilns when any of these are employed.

Some of the kilns visited were charged either by wheelbarrows or by hand. These methods are very slow and laborious, but are used apparently because the design of the kiln makes it impossible to use any other.

The buckets or cars brought to a kiln by an aerial cable are dumped by being lowered till they catch on a horizontal tripping device over the kiln and are upset. When a carload of stone is dumped into a kiln the larger pieces will stay where they strike while the smaller ones will roll away. Consequently considerable difficulty is experienced when side-dump cars are used because the stone in one side of the kiln is larger than in the other. This can be overcome by using bottom-dump cars, which discharge in the center of the kiln; the fine stones roll to the outer edges and tend to check the draft, which is normally greatest there.

Lime burning is a continuous process. It is generally impracticable to store more than two days' supply of stone in the hopper of a kiln, and it is most economical to run the kiln at full capacity. Thus a steady and reliable stone supply is necessary. Kilns which are built without hoppers should, of course, be filled after each draw. Kilns with hoppers are generally filled once a day, or twice if the quarry or mine and hoisting apparatus are of sufficient capacity.

(b) ROTARY KILNS

Where rotary kilns are employed it is never practicable to dump directly from the cars or carts into the kilns. The stone has to be of a comparatively uniform size, about one-half to 1½ inches being the limits, for the most economical operation. This necessitates reduction and grading of the rock as it comes from the mine or quarry. Furthermore, a constant source of supply of rock for the rotary is demanded. To meet this demand storage bins, from which the graded rock may be drawn continuously, are required. The feed should be constant and the amount of stone to the kilns depends upon a number of factors, among the more important of which is the size of the kiln.

It has been stated that the rock to a rotary should be not smaller than one-half inch nor larger than 1½ inches. Experience has shown that, where it is possible to feed to the kiln stone of even smaller differences between the maximum and minimum sizes, not only a better product results, but the lime to fuel ratio is increased.

4. DETAILED DESCRIPTION OF KILNS

(a) GENERAL DISCUSSION

Practically all of the lime produced in this country to-day is burned in some form of kiln. What is known as the shaft kiln is most generally used, but in recent years the rotary kiln, well known in the cement industry, has come into extensive use. The use of the rotary kiln has been retarded somewhat because of the fact that when it is employed the product is of such size as to be unsalable as lump lime, its use being limited to the manufacture of hydrated lime and to a more recent form of quicklime termed "pebble lime." This latter product is quicklime averaging about 1 inch in diameter. However the demand for hydrated lime has so greatly increased in recent years as to have justified the installation of many rotary kilns.

Inasmuch as there are a great many varieties of shaft kilns in which the major portion of the lime manufactured to-day is burned, they will be given consideration first. In general, a shaft kiln resembles a short wide stack of either square, round, or elliptical cross section. It consists of a casing of steel or stone which is lined with refractory material. The long vertical chamber formed by this lining may be divided into three compartments by imaginary horizontal planes. The top compartment, called the hopper, is used for storing and preheating the stone. Its sides slope in so that the stone may slide down into the middle compartment, the shaft. This shaft is the place where the lime is burned. It may be of either square, round, or elliptical cross section independently of the outside of the kiln. Generally, the sides of the shaft are vertical, although in some cases they slope outward. In this latter method of construction it is customary to omit the hopper. At the bottom of the shaft the third compartment or cooler is used for storing the lime after it is burned. The top of the cooler must, of course, have the same cross section as the shaft. The sides are drawn in to form a slide leading to the drawing door. A hole in the side or bottom of the cooler is closed by a door or by sheets of iron which swing on a pivot and are known as shears. The lime is removed through this opening. The fuel used in burning the lime is consumed in the fire boxes usually arranged on two sides of the kiln. They are very similar to the common fire boxes in use under boilers. Each kiln has two or more which are set in openings through the casing and lining into the lower part of the shaft. In this paper the level of the grates in the fire box will be considered the bottom of the shaft, it being assumed that lime is not burned below this point. Whether or not this assumption is valid has not as yet been demonstrated. With gas or oil as fuel, ports through which they are led into the kiln are used in place of fire boxes. In either case the draft caused by the combustion of the fuel draws the flame up through the shaft in direct contact with the lime and stone and the gases formed pass out the top of the hopper. To increase this natural draft a stack is sometimes placed on top of the kiln. Forced or induced draft, or a combination of both, is also in common use. The forced draft is generally created by blowing steam through the grates into the fire box; the induced, by drawing the gas out of the top with a fan. These two methods may be combined, or the gas which is drawn from the top may be forced back through the grates, according to the Eldred process. These methods of increasing the draft have in some cases necessitated closing the top of the kiln. Hence, a charging door must be supplied through which the stone can be dumped. The various parts of the kiln are shown in Figure 2.

There are many considerations which limit the practical size of a kiln. Chief of these is probably the market which the kiln has to supply. Lime is a perishable article; hence any cessation in the demand necessitates a curtailment of supply. If the market demands a definite supply of lime for a continuous period, a kiln can be built large enough to supply that demand. Generally, however, it is safer to build a number of small kilns, so that in case the demand falls off it will not be necessary to close down the entire plant. A custom which is becoming very prevalent is to run the kilns at full capacity and hydrate that lime which can not be used immediately, for hydrate may be stored. The cross section of the shaft is limited by the distance the heat can be made to penetrate toward the center. The total height of the kilns above the grates is limited by the conditions of the draft. If natural draft is used, the gases must leave the top of the kilns hot enough to produce the draft; that is, the kiln must not be too high, or the stone will absorb too much heat from the gases. With any form of induced draft the kiln should be just high enough so that the gases which reach the top have approximately the same temperature as the external air. If the kiln is lower than this the heat carried off by the gases is simply wasted; if higher, the added amount of stone causes unnecessary work for the fan.

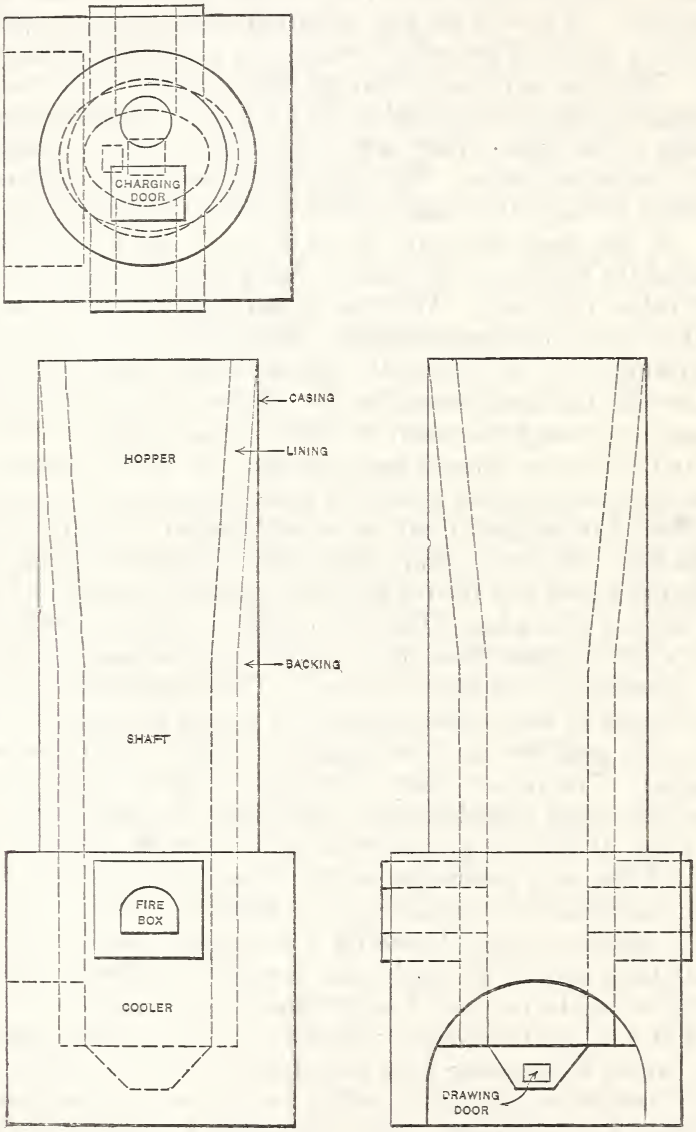

Fig. 2.—*Round kiln with shaft drawn in*

Although there are numerous designs of limekilns, they may be divided, for the sake of classification, into six types according to the outline of their shafts. These types are illustrated by Figures 2, 3, 4, 5, and 6.

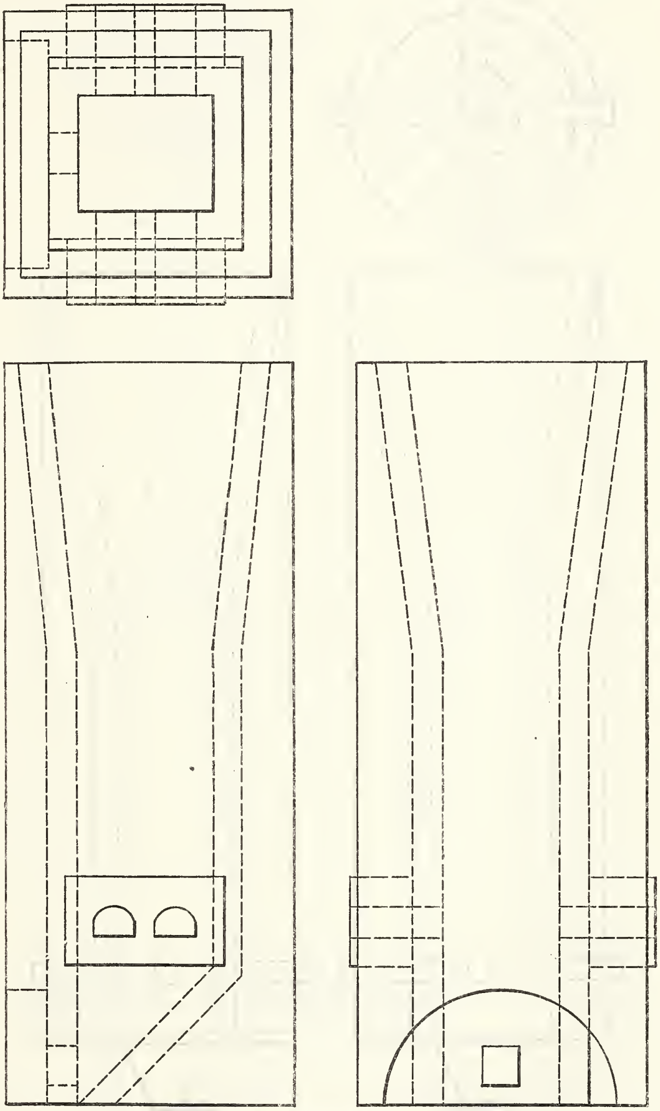

Fig. 3.—*Square kiln with straight shaft*

The drawings are not to be considered as of actual kilns, although there are kilns which are very similar to each of these types, but differ in some detail. These diagrams are intended to be merely composite designs, showing the more important points of variation.

It is, of course, understood that the component parts of these designs perform the same functions. The dimensions used in the drawings are the averages taken from the kilns investigated. Table 2 calls attention to the variations shown by these designs. In the next section each component part will be discussed in detail.

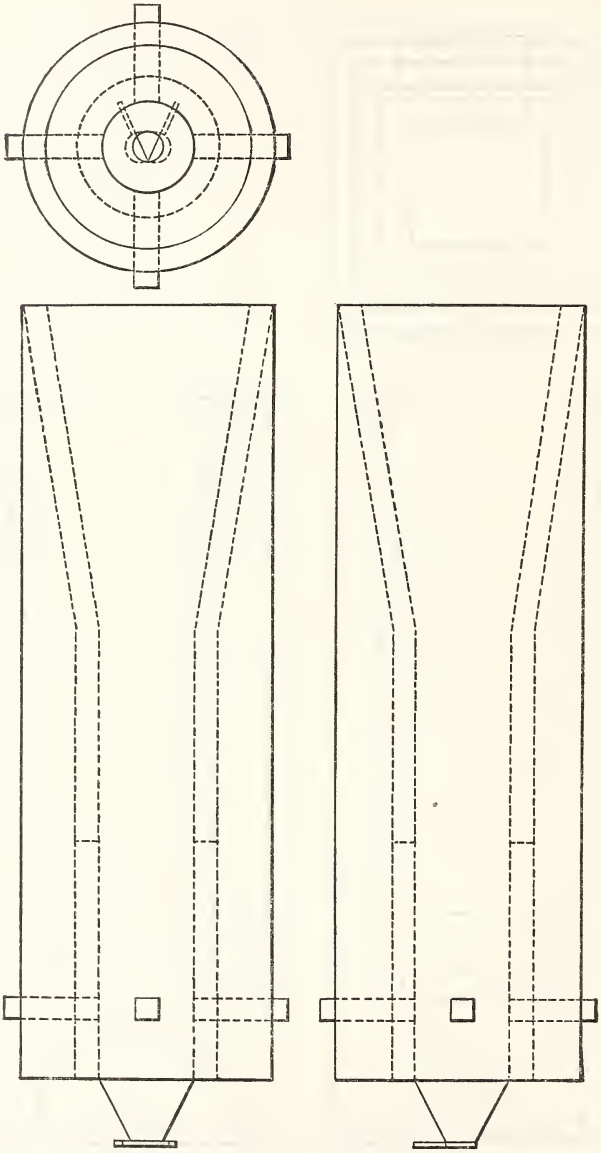

Fig. 4.—*Round kiln with straight shaft*

The rotary kilns which are used in the burning of lime are similar to those which have been successfully used for years in the manufacture of cement. The rotary kiln is essentially a steel cylinder of from 6 to 9 feet in diameter and from 60 to 200 feet in length and which is supported on trunnions and rotated. It is set in a slightly

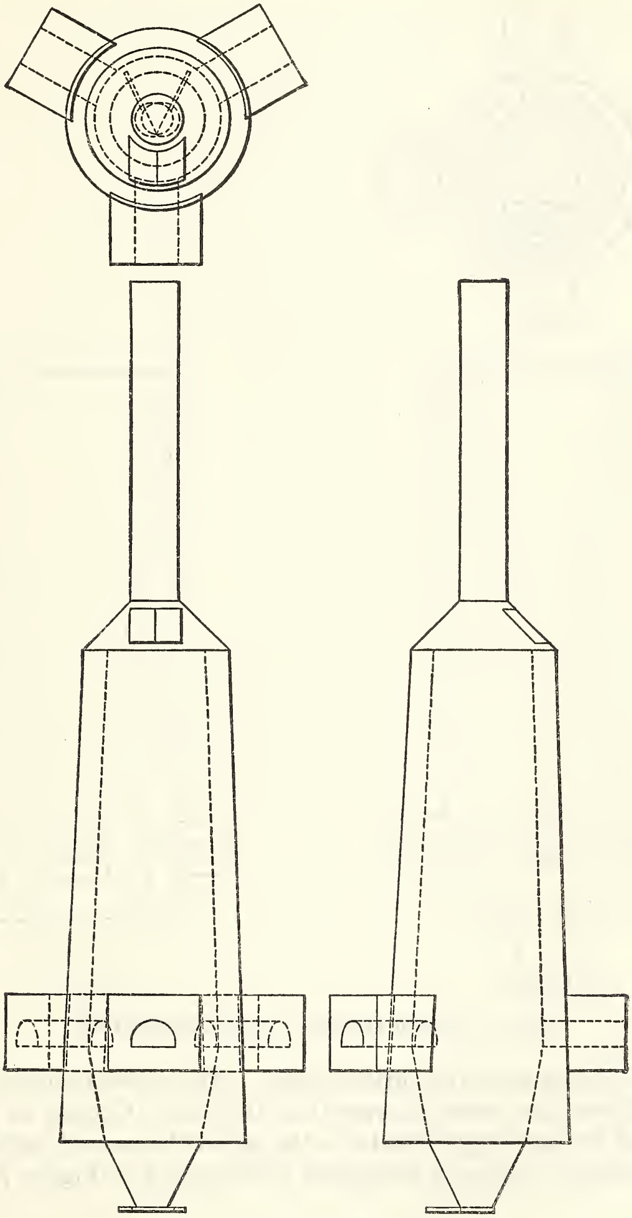

Fig. 5.—*Round kiln with flaring shaft*

inclined position, the inclination being usually about one-half inch to the foot. The rotating section is lined with some type of non-abrasive fire-resistive material. The crushed lime rock is fed into the upper end of the kiln, while the fuel, which may be powdered coal, oil, or gas, is forced in at the lower end. A draft is maintained usually by means of a fan. As the stone passes through the kiln it is burned, and at the lower end drops into a cooler. The cooler is also a rotating steel cylinder, but much shorter than the kiln. Cooling of the lime is effected by exposing it freely to the air in the second cylinder. A type of rotary commonly employed is illustrated in Figure 7.

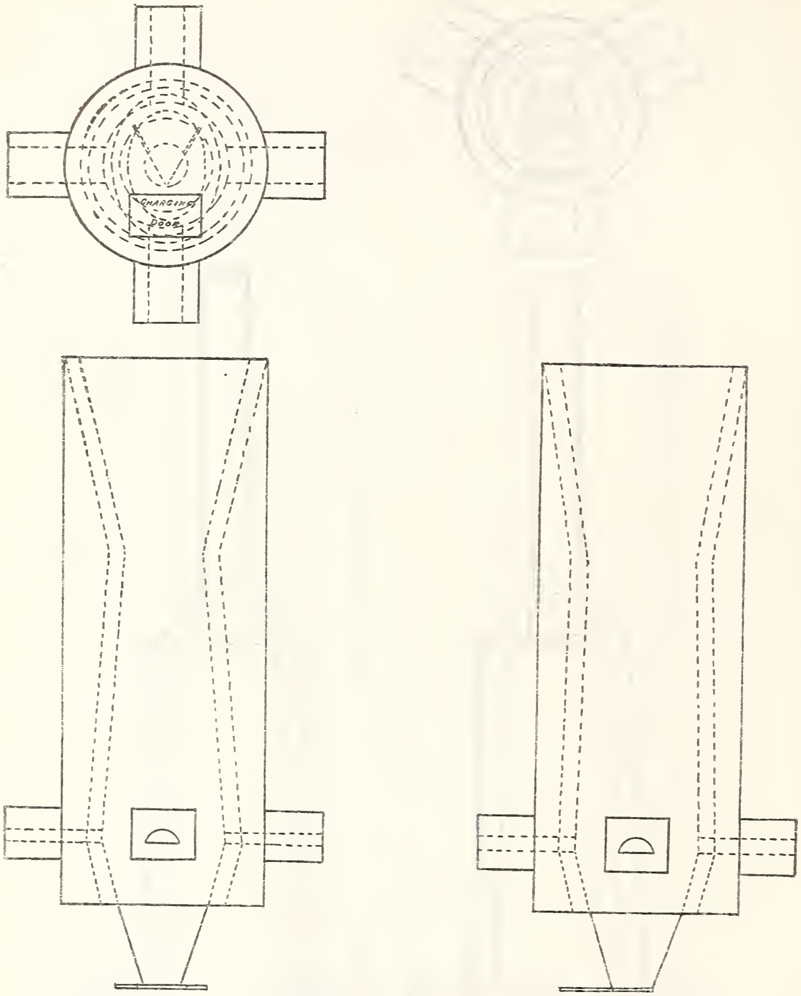

FIG. 6.—*Round kiln with distorted conical shaft*

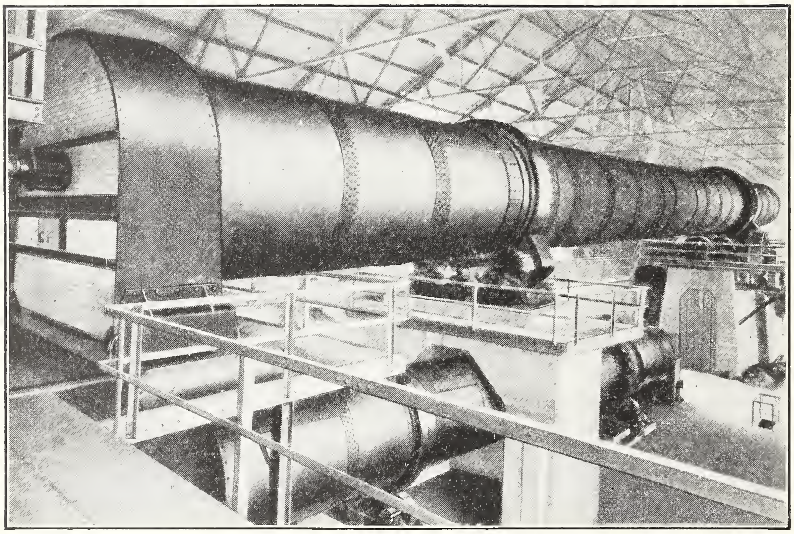

Fig. 7.—*Rotary kiln (100 by 5 feet) with rotary cooler (73 by 7 feet) showing firing hood*

TABLE 2.—*Variations in kiln design*

(Shown in figs. 2, 3, 4, 5, and 6)

Part of kiln	Figure 2	Figure 3	Figure 4	Figure 5	Figure 6
Casing	Part steel, part stone, brick or concrete.	Stone	Steel	Steel	Steel.
Lining	Fire brick	Fire brick	Two grades of fire brick.	Fire brick	Two grades of fire brick.
Backing	Steel section back	None	Has backing	None	Has backing.
Top	Closed	Open	Open	Stack	Closed.
Charging door	Flat	None	None	Inside of conical piece.	Flat.
Hopper	Circular at top, eliptical at bottom.	Square at top, rectangular at bottom.	Circular at top and bottom.	None	Circular at top. Elliptical at bottom.
Shaft	Straight, eliptical.	Straight, rectangular.	Straight, circular.	Conical	Distorted conical.
Cooler	Unlined	Lined	Unlined	Unlined	Lined.
Means of drawing	Door under center.	Door at side	Shears	Shears	Shears.
Number of fire boxes	Two	Four	Four eyes for producer gas.	Three	Four.

(b) DETAILS OF VERTICAL KILNS

(1) CASING AND BACKING.—The casing, or outside shell of a kiln in conjunction with the backing, has three distinct functions to perform. It must carry part of the weight of the kiln, it must protect the lining from excessive changes in temperature, and it must minimize the amount of heat lost by conduction and radiation. With regard to shape and material, casings may be divided into five classes:

(1) Square stone casings. (These are generally built one stone (9½ inches) thick at the top, extending straight down on the outside, and following the contour of the hopper shaft and cooler on the inside. They are illustrated in Figure 3.)

(2) Round steel casings as shown in Figure 4. (This is made of sections of steel plate, rolled to shape and bolted together. Instead of being circular in cross section, these casings are sometimes elliptical.)

(3) Conical steel casings. (This variation of (2), shown in Figure 5 is common enough to warrant consideration as a separate class.)

(4) A combination of steel with stone or other material. (In this case a cubical structure large enough to inclose the fire boxes is built of stone, brick, or concrete, and the steel casing is built upon it. This method of construction is illustrated by Figure 2.)

(5) A variation of (4). (In this case the fire boxes are above and independent of the stone, brick, or concrete structure as illustrated by Figure 6.)

With regard to the first requirements of casings—supporting the weight of the kiln—steel is probably more satisfactory than stone. The strain is practically all lateral, and the steel plates can give to some extent without losing strength, while if the stone is pushed out (as is often the case) it must be tied together with iron rods.

The loss of heat suffered by a kiln is due to two causes—conduction and radiation. The heat lost by conduction varies inversely with the thickness of the wall, and depends on the kind of material used. The material used should be as porous as possible. For example, in some work conducted by Wologdine and Queneau[17] it was shown that a 12-inch wall of porous fire brick would not conduct as much heat as an 18-inch wall of hard brick. The conductivity of ashes or diatomaceous earth is still less than fire brick. Therefore, steel casings backed with ashes or diatomaceous earth will theoretically offer greater resistance to the passage of heat than casings built of comparatively dense limestone. For an example to show the magnitude of the losses involved, assume that a kiln is 15 feet in external diameter and 40 feet high. The shaft is circular, 6 feet in diameter, and is lined with 18 inches of fire brick. The space between the casing and the lining is filled with ashes. The difference in temperature between the inside and outside of the kiln is 1,200° C. (2,192° F.) at the bottom and zero at the top. The conductivities of fire brick and ashes may be taken as 1.37 and 0.64 large calories, respectively, per hour per square meter of surface per 1 meter of thickness per 1° C. difference of temperature. Therefore, if the coal has a heating value of 3.276 large calories (13,000 B. t. u.) per pound, the total loss by conduction of such an installation will approximate 200 pounds of coal per day.

The other factor, radiation, is also of importance, and the same conclusion holds, namely, that the use of as porous a material as possible is desirable. However, this must not be carried to the extent of encouraging the use of large air spaces within the kiln walls, for air, although an effective nonconductor of heat, presents no obstacle to the radiation of heat which passes through it as would light (but the more and the smaller the air cavities the substance contains the better it is for the purpose). Since the rate of radiation is proportional to the fourth power of the difference in temperature between the hotter and colder bodies, it is readily seen that the heat radiated across the air space may easily become a significant factor. While air spaces in a wall may do for slight temperature differences and low initial temperatures, these conditions do not exist in a limekiln.

Dense substances, like limestone, conduct heat too rapidly; large air spaces permit the heat to be transferred by radiation; so that theoretically the best insulation will be obtained by the use of some porous material, such as ashes or diatomaceous earth.

The same reasoning which has been used in regard to the heat lost by conduction and radiation naturally applies also to the protection of the lining from excessive changes in temperature.

---

[17] Wologdine and Queneau, Electroch. Met. Ind., 7, pp. 383-389, 433-436; 1909.

From the above considerations it will be seen that steel, with a sufficient backing of some porous material, should fulfill the requirements of a casing better than stone. Moreover, it is probably cheaper if the cost of labor is taken into consideration.

The casings built partly of each material are compromises. The stone is used to inclose the hottest part of the kiln, and the steel where the chance of loss by conduction is not so great.

Table 3 shows how the above classes of casings are distributed among the kilns investigated, together with the more important dimensions.

TABLE 3.—*Dimensions of casings*

Class	Description	Number of kilns	Dimensions	Maximum		Minimum		Average	
				Ft.	*in.*	*Ft.*	*in.*	*Ft.*	*in.*
1	Square, stone	23	Length of side, external	20		12		14	3
			Height	50		29		40	
2	Round, straight, steel	134	Diameter	20	6	6	6	10	2
			Height	80		16		40	
3	Round, conical steel	15	Diameter at top	8		6		7	6
			Diameter at fire	10	6	8	6	9	4
			Height	43		19		36	7
			Height	43		19		36	7
4	Round, steel and stone, straight.	49	Diameter at top	16	6	7		11	
			Side of square at fire	18	6	15	6	17	6
			Height	52		23		60	

(2) LININGS.—The lining of the kiln is very important wherever lime is burned by the continuous process, and practically all of the lime produced in the United States is so burned. In this process the stone is continually charged in at the top of the kiln and the lime drawn out at the bottom. Therefore, to repair the lining, the lime must be drawn and the kiln allowed to cool down. This is very expensive, involving a loss of time, labor, heat, lime, and stone. For this reason the material used for lining should be such as will minimize the frequency of repairs.

In shape the lining conforms with the sides of the hopper, shaft, and sometimes the cooler; hence its dimensions will be discussed under these heads. It is commonly the custom to maintain the same thickness of lining throughout the kiln. If fire brick is used, about 8 inches (two courses) are generally considered sufficient. Other materials may vary in thickness from 9 to 18 inches.

In the burning zone (the fire boxes and lower part of the shaft) the material must resist a high temperature, and also the chemical action of the lime. Table 4 shows the way these requirements have been met at the plants visited.

TABLE 4.—*Materials used in lining kilns*

Burning zone of kiln material used	Number of kilns in which used	Upper part, material used	Number of kilns in which used
Fire brick	195	Fire brick (same grade as burning zone)	52
Sandstone	21	Fire brick (different grade)	114
		Paving brick	24
Mica schist	19	Granite	11
		Sandstone	30

The temperature in the burning zone probably seldom exceeds 1,400° C. (2,552° F.), a temperature which many grades of fire brick are able to withstand. The main difficulty seems to be caused by the chemical action of the lime. At the temperature attained the lime unites with some constituents of the brick to form compounds which fuse with comparative ease. In this respect practical results have shown that calcium oxide is much more corrosive than magnesia. Of the manufacturers consulted, only one seemed to think it possible to obtain a fire brick which would withstand the fluxing action of a high calcium stone for a period of time in excess of one year, although several grades have been used for much longer period than this with magnesian limes. There is, however, the possibility of obtaining brick of ample resisting power by the use of highly aluminous materials containing a sufficient amount of "grog." [18] Brick of this composition are obtainable; though they command a high price it would probably be economical to use them. A high-grade fire brick of this kind is superior to magnesite brick, since the latter, though very refractory and unaffected by the action of lime, is quite friable and subject to loss by abrasion at the temperatures involved.

The apparent failure of fire brick to meet the demands has led to experiments with mica schist and sandstone. Each of these materials has given satisfaction, but they may be more expensive than fire brick. Silica brick, which are a standard and relatively inexpensive commercial product, warrant consideration, in view of the experience with sandstone.

In connection with the manufacture of a brick for lining limekilns, the following analysis was made by Union Mining Co. (makers of the Mount Savage fire brick)

	Per cent
Loss on ignition	0. 86
Silica (SiO_2)	96. 36
Titanic acid (TiO_2)	. 14
Alumina (Al_2O_3)	. 95
Ferric oxide (Fe_2O_3)	. 55
Manganous oxide (MnO)	. 34
Calcium oxide (CaO)	. 38
Magnesium oxide (MgO)	. 22
Sodium oxide (Na_2O)	. 20
Total	100. 00

---

[18] Small pieces of broken, burned, brick.

For the upper part of the linings the problem is much simpler. At first it was the custom to use the same grade of fire brick throughout the kiln, but it has been found that a brick sufficiently refractory to give good results in the burning zone is too soft to stand the abrasion in the upper part of the kiln. Hence a number of kilns are lined with two grades of fire brick. Where granite and sandstone are used the materials are generally found on the premises. They are well able to stand the wear, but would probably be too expensive to cut and put on the market. Of the five materials mentioned in Table 4, paving brick is believed to be the best for the upper part of the lining. It is able to withstand the heat, is made especially for resistance to abrasion, and is probably cheaper than fire brick or cut stone.

(3). TOPS OF KILNS, STACKS, AND CHARGING DOORS.—There are three methods in common use for constructing the tops of kilns. Of the 231 kilns reported in this paper 91 have open tops, 87 have closed tops, and 53 are surmounted by stacks. Obviously a discussion of the open top is not necessary.

Closed tops are constructed of flat steel plates, bolted to the casings. They are used in connection with some systems of induced draft, and, therefore, should be kept practically air-tight, so that the fan which removes the gas need not handle any unnecessary air. Closed tops must be provided with two openings, one through which the gas is removed and another for the charging door. This door is generally about 3 feet wide by 5 feet long, and should be large enough to permit dumping in a carload (2 or 3 tons) of stone at one time. It may be either hinged or sliding, but care should be taken to see that it is closed air-tight after each charging. It is good practice to seal it shut with lime paste.

The stacks used are the ordinary round steel variety common in boiler practice. They are generally connected to the casings by short conical sections of steel. The charging door is cut in the side of this section, as shown in Figure 5, and herein lies the greatest objection to the use of stacks. Unless the kiln is of rather large diameter it is impossible to make the door of sufficient size and place it in such a position that a carload (2 or 3 tons) of stone can be dumped through it at one time. Of the 53 kilns with stacks only 22 are large enough for this purpose. To 4 of the others the stone is taken in wheelbarrows, the doors being sufficiently large to admit this smaller amount. The charging of 11 other kilns is done by hand. In order to eliminate this expensive method of charging, the conical section has been omitted from the remaining 16 kilns. The stacks of these project from flat tops which are similar to those used in the closed-top construction, and hence the charging doors offer no difficulty.

The dimensions of the stacks in use are as follows:

Diameter—maximum, 48 inches; minimum, 22 inches; average, 35 inches. Height—maximum, 40 feet; minimum, 10 feet; average, 23 feet 5 inches.

The principal reason for placing a stack on a kiln is to increase the draft, which assists in preventing the "recarbonating" of the lime. As explained in the section on burning, lime will become recarbonated whenever the partial pressure of the carbon dioxide rises above the figure given by Johnston's equation. Practice has shown that in open-top kilns a strong wind will sometimes blow the gas back into the kiln, thus forcing the products of combustion down into the cooler and causing a momentary increase in the pressure of the carbon dioxide with a possible consequent recarbonation of the lime. Stacks are effective in preventing this.

For whichever purpose the stack is to be used it must be large enough to deliver the gas without throttling. A stack not sufficiently large is worse than no stack at all. The volume of gas to be delivered may be calculated from the analysis of the stone and fuel and the amount of each used. Assuming that the amount of gas evolved from the stone is 47.69 per cent by weight,[19] that the combustion of 1 pound of the fuel will generate 17 pounds of gas,[20] and that the velocity of the gas shall be 787 feet per minute,[21] by substituting factors generally known by lime manufacturers in equations for chimney design, the height and diameter of the stack may be calculated.

The manner in which the stack is connected to the kiln is of great importance. It is a well-known fact that a right-angled bend offers great resistance to the passage of gas. Consequently, when the top is built flat the draft created by the stack may be entirely nullified by the two changes in direction which the gas is forced to take. Moreover, the eddy currents set up by these bends may force the gas back into the kiln, with the attendant recarbonation. Both of these considerations point to the advisability of using a conical section for connecting the stack to the kiln.

(4) Hoppers.—The hopper or upper part of a kiln is designed as a place where the stone can be stored and at the same time preheated by the waste gases from the kiln. It is advisable to have storage room for an extra supply of stone, in order that the kiln may be independent of failures of machinery, inclemencies of weather and the numerous other factors which may interfere with the regular operation of the mine or quarry. A hopper constructed as the upper section of the kiln will save one handling of the stone, and should add sufficiently to the preheating space to increase the efficiency of the kiln.

---

[19] Calculated for pure dolomite, since this will give the maximum amount of gas.

[20] Calculated for coal gas, allowing 50 per cent excess air.

[21] Christie, Chimney Design, p. 30.

Hoppers are built in the form of inverted truncated cones or pyramids. The larger base is at the top of the kiln, and from this the sides slope in until the cross section becomes that of the shaft. The cross section of the upper base is not limited by either size or shape, except that it must be small enough to give the sides a rather steep slope. Otherwise, the stone is apt to arch over and will not slide down into the shaft. The height of the shaft and hopper, together has already been discussed, but just where the division between the two shall take place is entirely arbitrary. Table V gives the forms and dimensions of the hoppers of 107 kilns.

Table V.—*Forms and dimensions of hoppers*

	Form	Dimension	Kilns	Maximum	Minimum	Average
				Ft. in.	*Ft. in.*	*Ft. in.*
Upper base	Square	Side of square	21	14	8 6	10 8
	Circular	Diameter	86	19	7	9 9
Lower base	Rectangular	Larger dimension	34	8	6	7 2
		Smaller dimension		7	5	6 3
	Elliptical	Larger dimension	73	16	5 10	6 11
		Smaller dimension		7 6	4 10	5 5
Height			107	37	5	15 6

It is generally agreed that stone sufficient to supply the kiln for 48 hours is enough to keep on hand. If, for example, a kiln produces 10 tons of lime per day, its hopper should hold at least 27½ cubic yards of stone. Hence, in designing a hopper the volume and the form and size of the lower base are fixed. The other dimensions may be varied at will, provided that the sides are sufficiently steep and the height is considered in connection with that of the shaft. The volume of the hopper may be calculated from the formula:

$$v=\tfrac{1}{3}h\ (a_1+a_2+\sqrt{a_1a_2})$$

where

v = volume of hopper,
h = height of hopper,
a_1 = area of upper base,
a_2 = area of lower base.

(5) Shafts.—The shaft is that part of the kiln in which the actual burning of the lime takes place. As the stone passes down through the shaft it is gradually heated until the temperature of calcination is reached. This occurs usually about 8 feet above the grates. Therefore, the upper part of the shaft serves as a preheating chamber and the lower part is known as "the burning zone."

The size and shape of the shaft depend very largely on the method by which the kiln is to be operated, and the following discussion should be considered in conjunction with section 5 on "Methods of operating shaft kilns."

The factors discussed in section 5 will determine whether the sides of the shaft should be vertical or slope outward. The height must be considered in connection with that of the hopper, as already indicated. It should be added, however, that the burning zone should always be included in the shaft, for the larger dimensions of the hopper offer too many opportunities for the formation of "chimneys," which might permit the gas to escape without transferring its heat to the stone.

With regard to cross section, shafts are constructed in three shapes, rectangular, elliptical, and circular. The economic design of the cross section depends upon the distance to which the heat can be made to penetrate toward the center of the kiln. For this reason the rectangular and elliptical shafts have their smaller dimensions between the fire boxes. The rectangular shaft is more easily constructed and repaired than the elliptical, but the corners serve as excellent "chimneys" for the gases, so that elliptical kilns should be more efficient. It is obvious that an elliptical shaft with its lesser diameter equal to the diameter of a circular shaft will have a greater cross-sectional zone of heating, and, therefore, a larger capacity. This reasoning would lead to the conclusion that the ellipse is the best shape for the cross section of a shaft. However, a circular shaft which is also readily constructed and repaired, may give equally good results if provided with three fire boxes.

In Table 6 are given the forms and dimensions of the shafts in the 233 kilns investigated.

TABLE 6.—*Forms and dimensions of shafts*

Sides	Cross section	Shape of cross section	Number of kilns	Dimensions	Maximum		Minimum		Average	
					Ft.	*in.*	*Ft.*	*in.*	*Ft.*	*in.*
Sloping			57	Height	55		8		31	
	At top	Circular	57	Diameter	9		4	6	6	
	At fire	do	25	do	9	8	6	6	7	8
		Elliptical	32	Large dimesion	7		6		6	10
	At top	do		Small dimension	6		5		4	4
Straight			176	Height	60		5		17	4
	At fire	Rectangular	36	Large dimension	16		6		7	4
				Small dimension	7		5		6	
		Elliptical	117	Large dimension	16		5	6	6	10
				Small dimension	7	6	4	6	5	
		Circular	19	Diameter	6	6	4	6	5	8

(c) DETAILED DESCRIPTION OF ROTARY KILNS

The use of rotary kilns for the burning of lime was undoubtedly hastened by the success attendant to this type of kiln in the manufacture of Portland cement. With its introduction in the burning of a dry, finely ground powder in the cement industry a method of utilization of the great quantities of fine material which always resulted in quarry operations was apparent. As previously stated, when attempts were made to burn rock of less than 4 inches in diameter in a shaft kiln, clogging of the draft occurred. Furthermore, the increasing demands for hydrated lime and for "pebble lime" which have developed only in recent years present uses for the burned product.

A general description of rotary kilns which are used in the lime industry has been given in section 6 (*a*), and the following is a detailed discussion of the component parts.

(1) CASING OR SHELL.—There is only one type of casing used in rotary kilns, namely, steel. It is made up of sections of curved plates riveted together. The kiln is usually supported by means of two heavy steel rings or tires which encircle the kiln near each end and which bear on steel rollers. The driving mechanism is placed at a point about one-quarter the length of the kiln. It consists of a series of gears which are run by a variable speed motor, and the speed of the motor is in turn controlled automatically by the amount of stone fed into the kiln.

In the two plants visited where rotary kilns were used they were 60 by 6 feet and 90 by 8 feet, respectively. However, it is believed that shell dimensions from 6 to 8 feet in diameter and from 100 to 125 feet in length are the most common.

The size of the kiln necessary for a given output depends primarily on the diameter of the kiln. On the other hand, the length of the kiln, because of mechanical reasons, is limited by the diameter. Obviously, a kiln of small diameter would not have the rigidity of a kiln of the same length but of greater diameter. From a consideration of heat conservation alone the best dimensions would be such that the temperature of the waste gases would only be sufficiently high to produce just the necessary draft in the chimney. In deciding upon the best layout, consideration must be given the cost of the heat losses and the cost of their elimination. As the equipment is heavy and the costs high in long kiln installations the tendency is toward short kilns and the use of waste heat boilers or preheaters for conservation of the waste heat.

(2) KILN LININGS.—While several types of kiln linings for rotary kilns have been tried with more or less success, experience has shown that "high alumina" brick are the most satisfactory. The requirements of a brick for the lining of rotary kilns are essentially the same as in the hot zone of shaft-kiln practice and inasmuch as these are discussed fully in section 4 (*b*), (2), it is not necessary to repeat them again.

In rotary kilns there is no "backing up" of the kiln lining as in shaft kilns. The brick are laid directly on the shell or casing, different thicknesses being used to effect desired insulation.

(3) Dust Chambers, Stacks, and Coolers.—In the manufacture of Portland cement a finely divided powder is fed into the kiln at the upper end, and losses no doubt occur by dusting. As the product progresses toward the discharge end a hard nondusting clinker is formed and the material falling into the cooler is practically dustless. In the burning of lime just the reverse is true; a dustless product (in the form of a clean, hard stone) is fed into the kiln, and as calcination proceeds, lime is formed and abrasion takes place with resultant increase in dusting. It is, therefore, necessary that every precaution be taken to prevent the formation of air currents at the discharge end of the kiln which would carry the dust back into the kiln. It may interfere with the flame, and is especially detrimental in this connection.

The amount of dusting varies from plant to plant and no doubt the sizing of the stone, together with its physical properties when burned, are the controlling factors. It has been found that the coarsely crystalline stones dust less than most other varieties.

The upper end of the kiln is located in a chamber for the recovery of dust. The shape of the chamber is usually rectangular, though other shapes may be employed. Baffles are located inside the chamber and the dimensions of the chamber should be such that the velocity of the gases is reduced sufficiently to deposit the greater percentage of the dust particles. The chamber is customarily built of brick and is equipped with a conveyor to remove the dust which has been deposited.

Beyond the dust chamber, and often on it, is located the stack for the production of the necessary draft through the kiln and chamber. Considerations governing the dimensions of stacks have already been discussed in section 4, (*b*), (3).

After the stone has been burnt it drops from the kiln into the cooler. This is simply a rotating, cylindrical, steel shell, employed to cool and recover some of the heat of the lime. It is usually both shorter and smaller in diameter than the kiln, is driven by a motor, and is carried on tires similarly to the kiln. The cooler is unlined.

5. METHODS OF OPERATING SHAFT KILNS

There are two methods in common use for operating shaft limekilns, which are known as the "following" and the "sticking" processes. By either process only a part of the lime is taken out at a time, since enough must remain to fill the cooler and so keep the unburned stone above the grate level. The "following" method is very simple. When the lime is drawn from the bottom of the kiln the remaining lime and stone slide down and fill up the space as would naturally be expected. The difficulty with the process lies in the fact that the stone will not burn evenly. Owing to the tendency of the flame and hot gases to pass up the side of the shaft, rather than to go into the center, the mass of unburned stone always extends down farther in the center than at the sides, as shown in Figure 8, *A*. It is obvious that if the stone falls down evenly the unburned portion in the center must be brought below the grate level before the burned stone at the sides can be removed from the burning zone. It is the custom to draw out enough lime so that the lowest part of the stone will reach to about the grate level and then take a chance on overburning the lime in front of the fires. A kiln, after being drawn by this method, is shown in Figure 8, *B*.

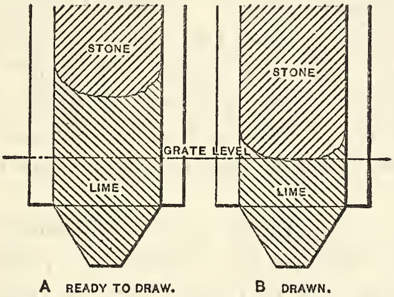

FIG. 8.—*Vertical sections of shaft, showing method of operation of "following" process*

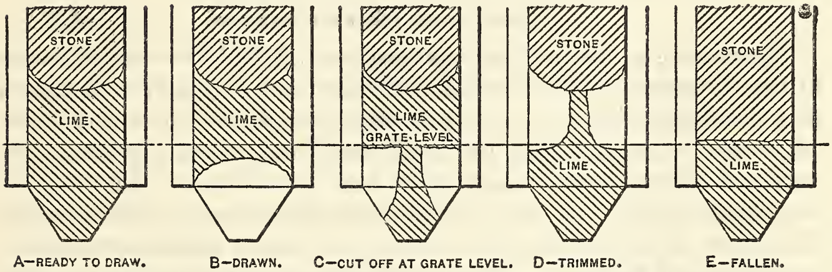

FIG. 9.—*Vertical sections of shaft, showing method of operation of "sticking" process*

The difficulty just explained may be obviated by the use of the "sticking" process. In this the kiln is generally chilled by omitting to fire and leaving the fire doors open for from 20 minutes to 1 hour before drawing. This chilling causes a contraction of the lining and also a solidification of the fused compounds resulting from the action of the lime on the lining. When the lime is drawn from the cooler these two processes acting together prevent the stone from following and cause it to "stick" or "hang" as shown in Figure 9, *B*. After drawing, the lime is knocked down by bars, inserted through the fire boxes, and finally the whole mass is caused to fall by knocking the supporting pillar of lime away. The stages of the operation are shown in Figure 9. By this method the lime can all be removed from the burning zone and an even layer of fresh stone is presented to the fire. It has great disadvantages, however. It requires altogether from one-half to one and one-half hours to complete the drawing, during which time no lime is burned, labor is expended, and the kiln is cooling down. Consequently, it is wasteful of time, labor, and fuel.

It must not be supposed that there is a hard and fast distinction between "following" and "sticking" kilns. In general, it may be said that if the sides of the shaft slope outward; that is, if the diameter is larger at the fire than at the top of the shaft, the kiln will "follow;" if straight, it will "stick." A skilled fireman can usually operate any kiln by either process, but sometimes kilns designed to "follow" will "stick," and vice versa. "Follow" kilns also have a troublesome habit of "turning over" at times; that is, something will cause a quantity of lime to stick in one part of the kiln, while the stone falls down past it, resulting in a layer of lime above some unburned stone.

To summarize, it apparently is more expensive to operate a kiln by the "sticking" than by the "following" process. Owing to the danger of obtaining core or overburned, or recarbonated lime, the "following" process probably gives a smaller capacity. The "following" process seems to be more economical, but the relative value of the processes has not been definitely determined.

(a) COOLERS AND DRAWING DOORS

The cooler, as the bottom compartment of the kiln is called, seems to be a necessary adjunct of all shaft kilns as every kiln investigated was provided with one. As generally constructed it is a pit into which the lime falls from the shaft and from which the lime is re-removed through an opening at or near the bottom. The sides of the cooler slope in so that the lime can slide down to this opening. The cross section of the cooler must, of course, conform to that of the bottom of the shaft. The only dimension remaining to be given, therefore, is the height, which, of the 160 kilns visited in 1913, was found to be as follows: Maximum, 14 feet; minimum, 4 feet; average, 8 feet 10 inches.

Since it may be assumed that the heat from the fire box never goes below the level of the grates on entering the kiln, it is necessary to keep all unburned stone above this level. The easiest way to do this is to leave enough lime in the kiln to support the stone at the required height. Hence, when a kiln is in operation the cooler is always full of lime.

The term "cooler" seems to be misapplied, judging from the method of construction commonly employed. In 132 kilns the coolers are lined exactly in the same manner as the lower part of the shafts, thus retarding cooling. Five others are lined, but are provided with air ducts, through which cold air is drawn into the ash pits. The 23 others are unlined—merely steel shells, exposed to the cooling effect of the air circulating around them. There is one advantage to be gained by lining the coolers: If, by chance, some stone should pass through the burning zone without being entirely calcined, the lining of the cooler has enough heat stored up in it to complete the operation. However, the cooler has a function of its own to perform without being obliged to assume that of the shaft. The cooler should actually cool the lime. If possible the heat so obtained should be utilized. This is best done by providing ducts of some kind in the lining, or pipes inside the cooler, through which the air used in burning the fuel may be drawn and thus preheated. If all the heat of the lime could be saved in this way, it would be equivalent to about 70 pounds of coal per ton of lime produced.

This saving of heat, however, is very insignificant when compared to the saving of time and labor effected by drawing the lime cold. When a lined cooler is used and the lime comes out hot, it must be dumped on the floor, cooled for several hours, and rehandled. If drawn cold, it can be dumped directly into the car for shipment, thus doing away with the cooling floor and diminishing the work of drawing and handling.

There are three devices in general use for drawing the lime. These are distributed among the kilns examined as follows: "Side-draw doors," 48; "center-draw doors," 19; "shears," 93. In constructing a side-draw door one side of the cooler is built vertical and the doorway is cut near the bottom of this side. This method has the grave disadvantage that it tends to draw the lime from that side of the kiln under which the door is placed. Consequently, the stone passes through the kiln faster on that side, and it is hard to maintain a uniform quality of product. This difficulty has been realized, so side-door draws are fast becoming obsolete. Center-draw doors are placed near the bottom of one side of a cooler, all of whose sides slope inward. Thus the door is very nearly under the center of the kiln and the difficulty experienced with side-draw doors is overcome. When shears are used, the opening is in the bottom of a cooler of which all sides slope inward. The opening, therefore, is under the center of the kiln. The shears themselves are two semicircular steel plates of such a size that they will cover the opening when their diameters are brought together. One end of the diameter of each is fastened by a pivot to the cooler. The other end is provided with a handle by which the two plates can be operated somewhat in the manner of ordinary shears.

(b) FIRE BOXES

The fire box or furnace in which the fuel is burned in limekilns is very similar in purpose and construction to those commonly used under boilers. It consists essentially of a grate surface spanned by an arch of fire brick, closed in front by a door, and opening into the kiln in the rear. There may or may not be a "dead plate" of solid cast iron in front of the grates. In limekiln practice it is customary to construct a bridge wall at the inner end of the grates and extending 6 inches or 1 foot above them. A pillar is sometimes put in, extending vertically from the center of the bridge wall to the arch.

The principles of construction of the fire boxes have been worked out by experience in boiler practice, and they are in the main applicable to limekilns as well. Of these principles the following may be noted:

The area of the grates should be designed with regard to the quantity and quality of coal to be burned on them and the amount of the draft. It is customary to allow 1 square foot of grate surface for from 12 to 15 pounds of bituminous coal per hour. It is better to make the area too large than too small, for with a high rate of combustion there is some tendency to overburn the lime. In all kilns except those in which the shafts slope outward, to prevent loss of heat by radiation, it is the practice to build the fire boxes inside the casings. Consequently, the depth of the fire box is limited by the thickness of the kiln wall. The arch should be high enough to give plenty of room for the combustion of the gases given off from the coal, and during operation the arch should be kept hot to avoid any possibility of chilling the gasses and preventing their ignition.

In order to keep the arch hot the fire door should fit fairly closely. With some grades of coal it seems necessary to admit a little air through the door to insure complete combustion, but the amount should never be large enough to cool the arch. When forced draft is used there is some tendency for the fumes to come out through the door, causing high repair cost. This can generally be remedied by proper regulation of the draft. The doors should be wide enough so that all parts of the grates can be reached easily to prevent the occurrence of dead corners at the front of the fire box.

A large dead plate is necessary for burning gas coal when the coking system is used in firing. By this method the fresh coal is put on the dead plate and the gases are distilled off and forced to pass over the fire. When the coal is coked it is pushed back on the grates and a fresh charge put in its place.

The bridge wall is extended above the grate level, so that there will be no danger of pushing ashes back into the kiln, where they might fuse with the lime and impair its quality.

The pillar is intended to support the arch, but is not very successful in performing this function, for it is generally the first part of the kiln to burn out. It does, however, tend to prevent the lime from falling into the fire box by partly closing the opening into the kiln.

Fire boxes for burning wood are similar in every respect to those in which coal is used, except that they are somewhat larger.

The following are the more important dimensions of the fire boxes in the kilns visited in 1913:

Dimension	Maximum	Minimum	Average
	Ft. in.	*Ft. in.*	*Ft. in.*
Height from grate to top of arch	3	1 6	2 4
Depth (including dead plate and bridge wall)	7 9	3	4 10
Width	6	2	3
	Sq. ft.	*Sq. ft.*	*Sq. ft.*
Area of grates	25	6	11.5

6. METHODS OF OPERATING ROTARY KILNS

In the operation of rotary kilns comparatively few details need be considered. However, such items as drying, cleanliness of stone, size of stone, and dusting probably justify attention.

Experience has shown that practically all limestone, as it comes from the mine or quarry, contains an appreciable amount of moisture and that, at certain times, quarried material has adhering to it a considerable quantity of extraneous material. After crushing, the smaller sized particles retain a greater percentage of moisture because of their greater surface area, and in many cases the installation of a rotary dryer has been justified, especially for drying the fine stone. Clay and mud on the stone going to a rotary kiln are apt to cause more trouble by the formation of siliceous calcium compounds because of the greater relative area of the pieces of stone. Therefore the cleanliness of the stone is of such vital importance in rotary kiln operation that the stone either must be cleaned or a method of winning clean stone, such as by mining, used.

The best size of stone for burning in all rotary kilns has not been determined. While conditions in specific plants may make other sizes desirable, stone from one-half to 2 inches has been found satisfactory in practically all rotary kiln installations. On the other hand, it should be appreciated that grading the stone so that it is all approximately of the same size results in greater uniformity of product and, conversely, less overburned lime and "core."

The dusting in rotary-kiln operation has been referred to in section 4, (*c*), (3), and mechanical means for its control discussed. It is believed that additional methods of controlling this nuisance, such as the operation of the kiln and mechanical appliances in the stack, demand consideration because of the disagreeable effects of the dust in the immediate vicinity and also in view of the enormous amount of material so lost.

(a) FEED

The feeding of the limestone to the kiln in rotary installations is so simple that it in no way compares with the cumbersome charging methods of shaft kilns. The stone is reduced and graded to the desired size and is feed into the kiln from a bin, commonly styled the "stone bin," whose discharge opening is located above the upper end of the kiln. An adjustable feeder controlled by the speed of the kiln and usually connected to the kiln gearing allows the stone to fall into an inclined chute which directs it to the interior of the kiln. The chute, or feed pipe, demands some attention in design and installation or it will cause trouble because of sagging under influence of the heat. Obviously more trouble is experienced in this connection with short kilns than with long ones.

(b) DISCHARGE

The burned lime is discharged from the lower end of the kiln through an opening in the under part of the hood and into a chute which directs it to the cooler. This is an unlined cylinder of sheet steel mounted in a manner similarly to the kiln. When rotary calcination was introduced in the lime industry the type of coolers employed were in every respect similar to those used in cement manufacture. It was soon found that the excessive amount of dust swept up into the flame from such coolers was very injurious, and it has led to the division of the interior of the coolers into four segments with the cooling of the lime accomplished by contact with the metal rather than by an air current. On the other hand, if the dusting in the cooler is not sufficient to interfere with the flame there is no reason why shelves or Z-bars may not be used to lift the burned lime up the side of the cooler, allowing it to fall back through the cooling air. At the lower end of the cooler the lime is discharged to a conveyor which takes it either to the hydrate mill or to storage bins. Coolers are usually from 4 to 5 feet in diameter and from 35 to 50 feet in length and are driven at a constant speed.

(c) FIRING AND FUEL

The successful firing of a rotary kiln depends primarily on a uniform supply of heat. If there is a variation in the heat supply the quality of the lime will be seriously affected and the output of the kiln materially reduced.

While the availability will probably dictate the kind of fuel to be used in a rotary installation it is feasible to use coal, oil, or gas (natural or producer).

In the first rotaries used for lime burning crude oil was employed because of their location. This was not found to be entirely satisfactory because of the short and excessively hot flame produced, but its use has been facilitated recently by the development of burners which have diminished or eliminated completely these difficulties. Powdered coal is also used for fuel in some instances and has been found entirely practicable. The use of a separate plant for pulverization, such as is employed by Portland cement manufacturers, has not been justified in lime burning, and, in consequence, the self-contained pulverization and injection unit is more widely used. If coal is burned, one of low ash and low sulphur content should be selected. Producer gas is at the present time the most universally employed fuel for rotary kilns. Since uniform firing is essential, it follows that hand-operated producers are not as satisfactory in this connection as mechanically operated ones. It is also much better practice to use two small producers on a single kiln installation than one producer sufficiently large to take care of the usual demand. If two kilns are operated, the use of three producers gives the best results.

7. METHOD AND TIME OF DRAWING AND SORTING THE LIME IN VERTICAL KILN OPERATION

There are some kilns still in use which have side-draw doors located at the ground level, so that the lime must be shoveled out. By far the majority of kilns, however, are built with the draw doors 3 or 4 feet above the floor. Iron barrows are pushed underneath and the lime is merely poked loose and allowed to fall into them. Recently several conveyor systems for handling the quicklime from the kiln have been installed and dump cars on tracks substituted for the barrows or buggies.

The barrows or buggies are built in two sizes, to hold about 250 or 1,000 pounds, respectively. The smaller size is similar to an ordinary wheelbarrow; the larger has two wheels and is dumped by removing the tailboard. The larger size is to be preferred, since by its use a kiln can be drawn in less time.

If the lime is drawn cold it may be loaded into the freight car immediately. If drawn hot it must be cooled either by letting it stand in the barrows or by dumping it on the cooling floor. It is always desirable to construct the kiln so that the lime comes out cold, but if this is not practicable, the former method of cooling is the less laborious one.

Lime is sorted either while being drawn or when it is taken up from the cooling floor. The object of sorting is to remove all unburned stone or overburned lime. In some localities, also, the consumer requires that the fine stuff be removed from the lump lime. This requirement is based on the opinion that the fine lime is air-slaked, a fallacy the untruth of which is rapidly being recognized. If the lime is to be sorted as drawn, the fine stuff can be taken out by grates in the bottom of the cooler. When a cooling floor is used the coarser stuff is generally removed by forking, leaving the fine stuff on the floor. Underburned stone and overburned lime can be distinguished from good lime by appearance. They can be picked out of the barrows or the conveyors while drawing or they may be dumped on the cooling floor with the lime and sorted when cold.

The time at which a kiln should be drawn depends upon the design of the kiln, the method of firing, the personal equation of the fireman, the quality of the stone, and the facilities for drawing. Therefore, while not always the case, an arbitrary interval is usually established between drawings at each plant, and very little experimental proof is at hand to show that the interval selected is the best for the conditions obtaining. Of the 231 kilns visited:

6 are drawn every 1 hour.
5 are drawn every 2 hours.
6 are drawn every 2½ hours.
29 are drawn every 3 hours.
112 are drawn every 4 hours.
53 are drawn every 6 hours.
15 are drawn every 7 hours.
3 are drawn every 8 hours.
2 are drawn continuously.

After the lime has been completely burned any further heating tends to impair its quality. The conclusion reached from this is that the lime should be kept moving through the kiln and drawn as frequently as possible. On the other hand, every time the drawing door is opened a large amount of cold air rushes into the kiln, causing a loss of heat. At many plants, especially where cooling floors are used, the facilities for drawing are such that it would be impracticable to draw much oftener than every three hours.

It is a well-known fact that every kiln has its individual method of operating and that the same kiln works differently on different days. Consequently, where competent firemen are available it would, perhaps, be advisable to let them decide when a kiln should be drawn, just as they are now depended upon to say how much lime shall be taken out.

IV. HEAT UTILIZATION AND EFFICIENCY

1. FUELS

It is hardly within the scope of this paper to discuss the theory of combustion of fuel, so only those points will be noted which are of practical importance to lime manufacturers.

Of the 231 kilns visited, 31 are fired with wood, 154 with coal, 16 with coal and wood mixed, and 30 with producer gas.

Wood has long been recognized as the best fuel with which to burn lime, and is used wherever it can be obtained with any degree of economy. The number of such localities is rapidly growing smaller, so that the problem of using some other fuel is of increasing importance. Experience has shown that wood results in a larger kiln capacity and a better quality of lime, and requires less care in the operation of the kiln than coal. Therefore the tendency of experiments with the latter fuel has been to modify the normal coal fire so that it will to some extent resemble the combustion of wood.

A wood fire has three characteristics which distinguish it from a coal fire in its adaptability to lime burning. First, its flame is longer. This enables the heat to penetrate farther toward the center of the shaft and creates a larger burning zone. Therefore, the capacity of the kiln is greater and the lime tends to burn more evenly, causing less difficulty in the operation. The amount of water generated by burning wood is much greater than that from coal. The presence of this steam in the products of combustion lowers the temperature required for calcination, [22] and this lengthens the burning zone and increases the capacity of the kiln. The flame from a wood fire is cooler than that from coal. This, in connection with the effect of the presence of steam, results in less danger of overburning and a better quality of product.

In all kilns where wood is burned natural draft has been found satisfactory.

The easiest way of modifying a coal fire so as to cause it to resemble the combustion of wood is to use a mixture of wood and coal. This works successfully wherever tried, but even the small amount of wood needed is not economically obtainable in many localities.

Many lime manufacturers are, therefore, forced, much against their will, to use coal for their fuel supply. The reasons cited above show why the coal fire should be modified to resemble the wood fire, and it may be added that in many instances the normal combustion of coal has proven distinctly unsatisfactory for the burning of lime. Experiments on modifying the fire have been mostly confined to different methods of producing the draft.

2. METHODS OF PRODUCING THE DRAFTS IN SHAFT KILNS

The following methods are in use at the kilns visited: Natural draft; forced draft, caused by blowing steam under the grates; induced draft, created by a fan which draws the gas from the top of the kiln; and the Eldred process, according to which a fan takes the gas from the top of the kiln and forces as much of it as is required back under the grates. In order to determine the relative efficiencies of these processes a number of heat balances were made. For this purpose six plants were selected, each being typical of one method of burning coal. At each plant observations were made extending over 48 hours, in order to determine those factors which are necessary for the calculation of the fuel efficiency. From the data so obtained heat balances have been constructed which show (1) how much heat was put into the kiln and from what source it was derived, (2) how much of it was actually required and the purposes for which it was used, and (3) the quantity of heat lost and the manner in which it escaped. The "heat efficiency" is the ratio (expressed as per cent) of the heat used to the heat put in. The heat

---

[22] S. V. Peppel, Bulletin No. 4, Geological Survey of Ohio, p. 294; 1906.

used is taken to include only the amount actually required for the calcination of the stone. Practically, sufficient heat must also be supplied to raise the stone to the calcination temperature and to create sufficient draft to remove the gases evolved. Theoretically, however, the stone must be raised to the required temperature only once, successive charges of stone being heated by the cooling of the lime and gas from the first charge; and no draft is necessary where the pressure at which the reaction takes place is not limited. A less exact but more used method of expressing the heat efficiency is by means of the "fuel ratio." This is the ratio of the pounds of lime produced to the pounds of coal burned. The fuel ratios given have been made a little more accurate by using, not the actual pounds of coal as fired but the pounds of coal equivalent to the total amount of heat put in. The figures are still of small value for the comparison of different plants, because variations in the stone will cause variations in the quantity of heat required to burn it, and different coals have different heating values. For this reason the "theoretical fuel ratio" has been calculated for each plant, in order to make allowances for the variations in the stone and coal. The plants selected all manufacture high calcium limes, but at the first plant a test was also made on a dolomitic lime for purposes of comparison. The capacity per kiln day depends on many factors, chief of which is the size of the kiln. No attempt has been made to compare the capacities of the different plants, but the figures are given with the idea that they may throw some light on the cost of the erection of the kiln.[23]

---

[23] The following data are used in calculating the heat efficiencies. They are not to be regarded as scientifically accurate, but as approximations close enough for the work in hand:

Heat of combination

Carbon to carbon dioxide, 14,500 B. t. u. per pound.
Carbon monoxide to carbon dioxide, 4,396 B. t. u. per pound.

Heat of dissociation

Calcium carbonate to calcium oxide and carbon dioxide, 693.6 B. t. u. per pound.
Magnesium carbonate to magnesium oxide and carbon dioxide, 520.6 B. t. u. per pound.

Densities of gases at 760 mm pressure and 32° F.

	Pounds per cubic foot	Cubic feet per pound		Pounds per cubic foot	Cubic feet per pound
Carbon dioxide	0. 1226	8. 15	Oxygen	0. 0892	11. 20
Carbon monoxide	. 0780	12. 81	Nitrogen	. 0783	12. 77
Sulphur dioxide	. 1788	5. 59	Steam (at 212° F.)	. 0379	26. 36

Specific heats

Limestone	0. 217	Water vapor	0. 48
Lime	. 217	Sulphur dioxide	. 155
Carbon dioxide	. 217	Oxygen	. 217
Carbon monoxide	. 248	Nitrogen	. 244

It must be emphasized that neither the data measured nor the calculations made therefrom are more than approximate. This would be impossible to attain with our present methods of measuring the quantities involved and our knowledge of thermochemistry. It is possible, however, to obtain results sufficiently near the truth to be of practical value, and while the calculations here given could probably be made more nearly exact, no additional information of practical value would be obtained thereby.

3. RESULTS OF KILN TESTS

A preliminary survey of each plant indicated what data it was necessary to obtain in order to calculate the heat balance. One kiln was selected for the investigation which, in the opinion of the foreman or superintendent, was giving the most satisfactory results. Some of the data, such as the speed of the fan, size of steam nozzle, etc., were constant throughout the test and were determined once for all. Other data, such as the weight of the stone, lime, or coal, were determined at irregular intervals, governed by the time of charging, drawing, or firing. The data which were variable were determined once an hour for 48 hours, and the results were averaged in order to obtain the values used in the calculations.

The temperature of the air was measured by means of a thermometer; all other temperatures by means of a platinum-rhodium thermocouple. The gas analyses were made on the spot with an Orsat-Muencke gas analysis apparatus. The draft was measured by means of a water draft gauge, reading directly to hundredths of an inch. Wherever fans were driven electrically, it was possible to measure the actual power used by means of a wattmeter. In other cases the maker's rating was relied on and was changed to allow for the noted change in speed. Samples of stone, coal, and ash were collected and shipped to the bureau for analysis. The stone was analyzed in the laboratory of the bureau under the direction of P. H. Bates, the coal and ash in the coal laboratory of the Bureau of Mines under A. C. Fieldner.

With the exception of plants 1 and 6 the results are believed to give a fair comparison of the different kilns under normal working conditions. The results seem to indicate that plants 2 and 6 were not being run with the maximum efficiency of which their equipment is capable.

(a) PLANT 1.—ROTARY KILN, FIRED WITH PRODUCER GAS

Description of plant.—The stone is brought from the quarry in cars, from which it is fed by hand into a gyratory crusher, which breaks it to about 1 inch and smaller. A bucket elevator takes it to a storage bin, whence it is delivered by gravity to a plunger which feeds it at a regular rate on to a belt conveyor. This delivers it to a bucket elevator which discharges into the upper end of the kiln. After passing through the kiln the lime drops into a rotary cooler. From this it drops to a belt conveyer which takes it to a rotary screen. This screen is about three-eighths-inch mesh and is used to sort out the core. The theory is that any pieces which have not been broken by their passage through the kiln and cooler so that they will go through this screen are not lime but consist chiefly of granite or other impurities. The tailings of the screen are therefore thrown away.

The lime passes through the screen into an automatically dumping bucket. This measures the lime and delivers it to a bucket elevator, which takes it to a storage bin for either hydration or shipment.

The coal is gasified in a Marten's gas producer. This is equipped with a hopper holding about enough coal for two hours' run, which feeds automatically into the producer. The draft is supplied by a steam jet. The pressure of the steam used is indicated by a gauge about 10 feet from the opening. The air for combustion of the gas is taken in through the rotary cooler. It is thus preheated by the waste heat from the lime and meets the gas at the entrance to the kiln.

The gases from the stone and the products of combustion pass from the upper end of the kiln through a dust collector and a water-tube boiler. They then divide into two parts. One part is permitted to escape through the "boiler stack"; the other is drawn through an economizer by a Sturtevant rotary blower and is blown out of the "economizer" stack.

A small amount of coal is fired directly on the grates of this water-tube boiler. The feed water is drawn from a storage pond by means of a feed-water pump, and is forced through a closed feed-water heater and an economizer before entering the boiler. The steam generated is used to furnish power for the entire plant.

Description of tests.—This test was divided into two parts. Dolomite was burned during the first part and calcite during the second. The plant does not show its maximum or even normal efficiency, because the kiln had just been relined and required to be heated up very slowly. Moreover, the locomotive which hauls the stone from the quarry was out of commission, so that the kiln had to be run below its normal capacity in order to prevent the supply of stone from giving out.

Samples of stone, coal, and ash were collected and shipped to the bureau for analysis. The following readings were taken once an hour for 48 hours: Temperature of boiler feed water, taken by means of a thermometer suspended in the pond at the opening of the intake pipe; boiler pressure, read from the gauge on the boiler; strokes of feed-water pump, counted for five minutes; wheelbarrows of coal fired on the grates of the boiler; temperature of the external air; temperature of stack gases from boiler; temperature of stack gases from the economizer; number of hoppers of coal fed into the producer; number of buckets of lime produced, counted for five minutes; pressure of steam blown into producer; analysis of stack gases from the boiler; analysis of stack gases from the economizer.

Analysis of stone

	Dolomite	Calcite
Silica (SiO_2)	0. 51	2. 95
Magnesia (MgO)	20. 86	1. 62
Alumina (Al_2O_3)	. 19	. 75
Iron (Fe_2O_3)	. 25	. 20
Lime (CaO)	31. 40	52. 26
Carbon dioxide (CO_2)	46. 32	41. 54
Water (H_2O)	. 38	. 61
Total	99. 91	99. 93
Calcium carbonate ($CaCO_3$)	56. 07	93. 32
Magnesium carbonate ($MgCO_3$)	43. 81	3. 40
Total solids, nonvolatile	53. 21	57. 78

Analyses of coal

	Producer	Boiler
	Per cent	*Per cent*
Carbon (C)	77. 94	74. 55
Hydrogen (H)	5. 31	4. 98
Nitrogen (N)	1. 61	1. 45
Oxygen (O)	8. 32	6. 57
Sulphur (S)	1. 19	. 65
Ash	5. 63	11. 80
	100. 00	100. 00
Heating value (B. t. u. per pound)	13, 914	13, 230
Combustible in ash	. 29	17. 42

Calculations.—The heat put into this kiln is derived from two sources—the coal fired in the producer and the coal fired under the boiler. Part of this is used for the actual burning of the lime, part of it to create the necessary draft, and part of it to produce the power required to run the machinery. Some of it is lost by permitting some of the combustible to escape with the ash of the coal, some of it is carried off by the hot stack gases, and the balance is lost by radiation and conduction. Another source of loss—the heat carried off by the lime as drawn—has been eliminated at this plant by cooling the lime to the temperature of the air before drawing it.

(b) PLANT 2.—KILN USING ELDRED PROCESS

Description of plant.—This plant comprises 10 vertical shaft kilns. The stone is fed into the top, each kiln being filled up once a day. The burned lime is drawn out of the bottom once every four hours. In general, the kilns are supposed to "follow down"; that is, the stone is supposed to feed down by gravity as the lime is drawn out. Sometimes they are "stuck" intentionally, in order to clean them out, and frequently they stick of their own accord. In this event it becomes necessary to knock the lime down by means of bars inserted through the fire boxes. Each kiln has two fire boxes, one on each side, into which coal is fed by hand. The gases produced are drawn from the tops of the kilns and returned according to the

Eldred process. For this purpose three fans are used, each being driven by its own electric motor. One fan draws the gas from 5 kilns and blows it out of a stack. Another draws it from the other 5, delivers part of it under the grates of all 10, and blows the rest out of a stack. The third supplies the air for all 10. Each fire box is thus supplied with a mixture of air and gas, the proportion of each being regulated by means of dampers. This gas is inert so far as combustion is concerned. As it passes through the hot fire it is heated and some of it may be decomposed. When it enters the kiln it is cooled and its constituents recombine. In this way it serves both mechanically and chemically to transfer the heat from the fire box into the kiln. Theoretically, therefore, the use of the Eldred process should lead to higher fuel efficiency and lower repair costs.

Description of test.—The lime produced is drawn into iron buggies, each of which is weighed before being dumped on the cooling floor. The coal used is wheeled to the kilns in barrows which are filled to 200 pounds net weight from a storage hopper. The power used to run the fans was measured by a professional electrician. The test was conducted on one kiln only, so that the power measured will be divided by 10. The gas is delivered through an 8-inch pipe, and in order to estimate the quantity used, its pressure, temperature, and analysis were taken. The data include also the temperature and analysis of the stack gases, the temperature of the air, and the temperature of the lime as drawn. The weight of coal was taken each time a fresh lot was wheeled to the kiln and the weight and temperature of the lime was taken at each draw. Other readings were taken once an hour for 48 hours. The pressure of the Eldred gas is the pressure due to its velocity. It was measured by inserting two three-fourth-inch pipes into the main. Each pipe ended in an elbow, one of which opened in the direction of flow and the other in the opposite direction. These pipes were attached to the opposite ends of a draft gauge, so that the pressure indicated was the difference of pressure in the two pipes.

Analysis of stone

	Per cent
Silica (SiO_2)	0. 25
Alumina (Al_2O_3)	. 03
Iron (Fe_2O_3)	. 27
Lime (CaO)	45. 77
Magnesia (MgO)	8. 81
Carbon dioxide (CO_2)	44. 06
Water	0. 97
	100. 16
Calcium carbonate ($CaCO_3$)	81. 73
Magnesium carbonate ($MgCO_3$)	18. 50
Total solids (lime)	55. 13

Analysis of coal

	Per cent
Carbon (C)	73. 10
Hydrogen (H)	4. 85
Nitrogen (N)	1. 46
Oxygen (O)	7. 92
Sulphur (S)	1. 32
Ash	11. 35

Heating value, B. t. u. per pound, 13,005.
Combustible in ash, 38.81 per cent.

Calculations.—The heat put in is derived from two sources: From the coal fired into the kiln and the heat equivalent of the power required to run the fans. Some heat is recovered from the gas which is taken from the top of the kiln and delivered under the grates. Part of this heat is used to burn the lime. Part of it is used to create the draft. Some of it is lost by permitting some combustible matter to be removed with the ash of the fuel. Some of it is carried off by the hot lime. Some of it is carried off by the waste gases. The remainder is lost by radiation and conduction.

(c) PLANT 3.—KILN USING THE SCHMATOLLA SYSTEM

Description of plant.—This plant comprises three vertical shaft kilns. The stone is charged in through a door in the top at frequent intervals, the aim being to keep the kiln nearly full all the time. The lime is drawn from the bottom every three or four hours. The kilns generally "follow down," that is, the stone feeds down by gravity as the lime is drawn out. They do "stick" occasionally, but this is not intentional. The coal used is charged from a storage hopper into a wood gas producer. Each kiln has its own hopper and producer. The draft for the producer is furnished by an electrically driven fan, one fan for the three producers. Water is fed into a compartment on top of the producer where it serves to cool and protect the top. The steam generated is carried into the producer by the air. The air required for combustion of the producer gas is admitted through the bottom of the kiln. It comes up in contact with the hot lime and meets the gas in the interior of the kiln. The products of combustion are drawn from the top of the kiln by an electrically driven fan, one fan for each kiln.

This plant is said to be run according to the Schmatolla system because of the method of admitting the air used for combustion. The forced draft into the producer and the induced draft from the top of the kilns are at variance with the Schmatolla system as generally understood.

Description of tests.—The weight of the coal was determined as follows: The dimensions of the hopper being known its volume can be calculated. The average weight of a cubic foot of coal was actually determined, so that the weight of a hopperful can be calculated. The hopper was filled to the top at the start, and was emptied completely. Coal was then wheeled to the hopper in barrows, the net weight and number of barrows being recorded. At the end, the distance from the top of the hopper to the top of the coal was measured. The weight of the stone can be calculated from the average net weight of a car and the number of cars. The power required to run the fans is taken from figures furnished by the company, which are believed to be reasonably accurate. The power used by the fan supplying air to the producers must be divided by three, because it supplies all three producers. The weight of water fed into the producer was determined by diverting the stream into a bucket for one minute and weighing the amount collected.

Analysis of stone

	Per cent
Silica (SiO_2)	1.08
Alumina (Al_2O_3)	.50
Lime (CaO)	54.00
Iron (Fe_2O_3)	.19
Magnesia (MgO)	1.13
Carbon dioxide (CO_2)	42.57
Water (H_2O)	.62
	100.09
Calcium carbonate ($CaCO_3$)	96.43
Magnesium carbonate ($MgCO_3$)	2.37
Total solids (lime)	56.90

Analysis of coal

Carbon (C)	78.22
Hydrogen (H)	5.45
Nitrogen (N)	1.78
Oxygen (O)	7.75
Sulphur (S)	1.13
Ash	5.67

Heating value, B. t. u. per pound, 14,004.
Combustible in ash, 9.73 per cent.

Calculations.—The total amount of heat is derived from two sources: From the coal charged into the producer and from the heat equivalent of the power required to run the fans. It is used to burn the lime and to create the draft. Part of it is lost by permitting combustible material to be taken out with the ash from the fuel and by drawing the lime hot. Part of it is carried off by the stack gases, and the remainder is lost by radiation and conduction.

(d) PLANT 4.—KILN USING FORCED AND INDUCED DRAFT

Description of plant.—This plant comprises five vertical shaft kilns. The stone is charged in through a door at the top at frequent intervals so that the kiln is kept nearly full. The lime is drawn out at the bottom every six hours. The kiln is "stuck" intentionally at every draw; that is, the stone does not feed down by gravity as the lime is drawn out but is made to arch over and support its own weight until it is knocked down with bars. It is claimed that by the use of this method the kiln can be kept in better shape and a better quality of lime can be produced. Each kiln is provided with two fire boxes, into which coal is fired by hand. Steam is admitted under each grate. This acts in a manner similar to the Eldred gas to carry the heat from the fire box into the kiln, and has an additional advantage in that it prevents clinkers from forming on the grate bars. The products of combustion are removed from the top of the kiln by means of a rotary blower, which is directly connected to a steam engine. This blower furnishes the exhaust for all five kilns.

Description of tests.—Each car of stone charged into the kilns was weighed. The weight of coal was determined by filling a bin with a known weight, using coal from this bin only, and weighing the amount left at the end of the test. The pressure of the steam used was measured by a gauge about 4 feet from the nozzle. The draft (of the exhaust) was measured by means of a draft gauge attached to the main leading from the top of the kiln to the fan. The zero reading was taken each time to correct for variations in temperature.

Analysis of stone

	Per cent
Silica (SiO_2)	0. 32
Alumina (Al_2O_3)	. 23
Iron (Fe_2O_3)	. 12
Lime (CaO)	54. 99
Magnesia (MgO)	. 65
Carbon dioxide (CO_2)	43. 34
Water (H_2O)	. 26
	99. 91
Calcium carbonate ($CaCO_3$)	98. 20
Magnesium carbonate ($MgCO_3$)	1. 37
Total solids (lime)	56. 31

Analysis of coal

Carbon (C)	73. 98
Hydrogen (H)	5. 19
Nitrogen (N)	1. 52
Oxygen (O)	7. 64
Sulphur (S)	1. 57
Ash	10. 10

Heating value, B. t. u. per pound, 13,259.
Combustible in ash, 28.09 per cent.

Calculations.—The heat used in this kiln is derived from three sources: The coal fired into the kiln, the heat equivalent of the power required to run the fan, and the heat required to generate the steam used. This heat is used to burn the lime and to create the draft. Part of it is lost, due to combustible in the ash. Part of it is carried off by the hot lime, and part of it by the stack gases. The remainder is lost by radiation and conduction.

(e) PLANT 5.—KILN USING NATURAL DRAFT

Description of plant.—This plant consists of six vertical shaft kilns. The stone is charged in at the top, each kiln being filled up immediately after the lime is drawn, day or night. The lime is drawn out at the bottom about every three hours. The kilns are designed and operated so that the stone will follow down by gravity as the lime is drawn out. The kilns will "stick" or arch over occasionally, however, and sometimes they are made to stick intentionally in order to clean them out. The kiln tested is equipped with four fire boxes, located one on each of the four sides. Coal is fired into these by hand. The natural draft is augmented by the use of stacks on top of the kilns.

Description of test.—The lime was drawn into iron barrows which were wheeled to the scales. Sufficient lime was added or taken off to bring the net weight to a definite figure. The number of barrows was tallied by an automatic counter attached to the scales. A number of barrows of coal of known weight were dumped into an empty bin. The coal used during the test was taken from this bin and the quantity remaining at the end of the test was wheeled out again and measured.

Analysis of stone

	Per cent
Silica (SiO_2)	0. 15
Alumina (Al_2O_3)	. 14
Iron (Fe_2O_3)	. 14
Lime (CaO)	55. 17
Magnesia (MgO)	. 37
Carbon dioxide (CO_2)	43. 52
Water (H_2O)	. 45
	99. 94
Calcium carbonate ($CaCO_3$)	98. 52
Magnesium carbonate ($MgCO_3$)	. 78
Total solids (lime)	55. 97

Analysis of coal

Hydrogen (H)	5. 07
Carbon (C)	72. 72
Nitrogen (N)	1. 87
Oxygen (O)	11. 11
Sulphur (S)	. 88
Ash	8. 35
	100. 00

Heating value, B. t. u. per pound, 12,980.
Combustible in ash, 36.05 per cent.

Calculations.—All of the heat used was derived from the coal fired. This heat was used for burning the lime and creating the draft. Part of it was lost, due to combustible in the ash. Part of it was carried off by the lime as drawn. Part of it was carried off by the waste gases and the balance was lost by radiation and conduction. It is considered that the heat carried off by the waste gases is utilized in creating the draft.

(f) PLANT 6.—KILN USING PRODUCER GAS

This plant consists of eight vertical shaft kilns, only three of which were in operation. The stone is charged in at the top at irregular intervals, the kilns being kept fairly well filled. The lime is drawn out at the bottom about every three hours. The stone is supposed to follow down as the lime is drawn out, but it sticks occasionally, and is sometimes made to stick in order that the kiln may be cleaned out. The eight kilns are supplied with fuel by three Duff gas producers, only one being in operation during the test. These producers are located at a considerable distance from the kilns, giving rise to a possibly large loss by radiation from the mains which may cool the gas to such an extent that it would become difficult to control its combustion. Each producer is run under forced draft, created by means of a steam jet, which draws in the necessary air. The gas enters the kiln through four ports. The air required for combustion is furnished by a blower and is mixed with the gas just as it enters the kiln. All of the air valves were open during the test, so that the fan was supplying sufficient air for eight kilns.

Description of test.—The figures of the company, covering a period of several years, have led to fairly accurate determinations of the average net weight of a shovelful of coal and a barrowful of lime. These factors, therefore, were used in determining the weights of coal and lime by merely counting the shovelfuls and barrows, respectively. The pressure of the steam blown into the producer was read from a recording gauge. Unfortunately, however, this gauge was about 30 feet from the nozzle, and there were three reductions and three bends between the gauge and the nozzle. The loss of presssure due to this resistance must, therefore, be calculated. A pressure gauge attached to the nozzle indicated about 65 pounds, but this gauge was known to be inaccurate. However, a calculation of the drop in pressure of steam flowing through this pipe shows that the loss would not be over 1 pound. This may be neglected and the pressure of the nozzle will be taken as that read on the recording gauge.

The temperature of the air was taken inside the kiln house, which explains why the stack gases were apparently cooler than the air. This test can hardly be considered fair to the plant because the kind of stone used during the test furnishes only about 5 per cent of the total annual output of the plant. The stone generally used is said to give a larger capacity with the same amount of fuel. The bell of the gas producer burned out during the test and had to be replaced. This necessitated shutting down the plant for a short while and resulted in the loss of one draw of lime.

Analysis of stone

	Per cent
Silica (SiO_2)	0. 13
Alumina (Al_2O_3)	. 21
Iron (Fe_2O_3)	. 19
Lime (CaO)	51. 85
Magnesia (MgO)	3. 42
Carbon dioxide (CO_2)	43. 88
Water (H_2O)	. 28
	99. 96
Calcium carbonate ($CaCO_3$)	92. 59
Magnesium carbonate ($MgCO_3$)	7. 18
Total solids (lime)	55. 80

Analysis of coal

Hydrogen (H)	4. 81
Carbon (C)	70. 29
Nitrogen (N)	1. 27
Oxygen (O)	7. 42
Sulphur (S)	1. 12
Ash	15. 09
	100. 00

Heating value of coal, B. t. u. per pound, 12,461.
Combustible in ash, 44.38 per cent.

Calculations.—The heat put into the system is derived from three sources: From the coal charged into the producer, from the steam blown into the producer, and the heat equivalent of the power to run the fan. It is used to burn the lime and to create the draft. Part of it is lost, due to the combustible in the ash. Part of it is carried off by the hot lime. Part of it is carried off by the stack gases. The remainder is lost by conduction and radiation.

(g) SUMMARY

Attention should be called to the following points: The efficiency is in all cases calculated as the ratio (expressed in per cent) of the heat actually used to burn the lime, divided by the heat put in, from the coal burned, the power to run the fans and the steam blown in.

The power used to run the fans has been calculated as the actual power used by the fans. No allowance has been made for losses in generating or transmitting this power, for these can not be fairly charged against the kiln. The method of calculating the heat balance credits the kiln with all the heat used, but does not consider whether or not the use of it was necessary. For this reason a fair idea of the economy of operation can be obtained only when the efficiency, heat balance and fuel ratio are considered in conjunction with the working conditions.

With this idea in view it may be profitable to criticise several of the items separately.

Summary of heat balances

Number	1		1		2		3		4		5		6	
Process used	Rotary kiln (using dolomite)		Rotary kiln (using calcite)		Eldred process		Schmatolla process		Forced and induced draft		Natural draft		Producer gas	
	Millions of B. t. u.	Per cent	Millions of B. t. u.	Per cent	Millions of B. t. u.	Per cent	Millions of B. t. u.	Per cent	Millions of B. t. u.	Per cent	Millions of B. t. u.	Per cent	Millions of B. t. u.	Per cent
Heat put in:														
1. From coal fired	[1]209.0 [2]61.9	100.0	[1]139.0 [2]28.6	100.0	146.0	99.9	531.0	99.6	148.0	95.5	208.0	100.0	157.0	99.3
2. From power for fans	0	0	0	0	.17	.1	1.9	.4	.1	.1	0	0	.03	.0
3. From steam blown in	0	0	0	0	0	0	0	0	6.7	4.4	0	0	[1] 1.0	.7
Heat used:														
4. To burn the lime	98.1	36.2	57.6	34.3	51.5	35.2	259.0	48.7	61.7	39.8	57.8	27.8	50.6	32.0
5. To create the draft	20.6	7.6	14.4	8.6	.17	.1	1.9	.4	6.8	4.4	31.7	15.2	1.1	.7
6. For power	33.5	12.4	19.8	11.7	0	0	0	0	0	0	0	0	0	0
Heat lost:														
7. By combustible in ash	1.7	.6	.8	.5	11.7	8.0	3.3	.6	6.4	4.1	10.9	5.2	21.8	13.8
8. By hot lime	0	0	0	0	.68	.5	5.4	1.0	12.4	8.0	1.8	0.9	1.55	1.0
9. By stack gases	49.6	18.3	22.0	13.1	35.8	24.5	122.0	22.9	37.3	24.1	3.7	1.8	20.9	13.2
10. By radiation and conduction (by difference)	67.5	24.9	53.4	31.8	46.3	31.7	141.0	26.5	30.4	19.6	102.0	49.2	62.1	39.3
Heat efficiency		36.2		34.3		35.2		48.7		39.8		27.8		32.0
Fuel ratio:														
Theoretical	11.4		10.7		9.85		10.45		9.74		9.45		9.25	
Actual	4.27		4.10		3 2.78		5.65		4.29		2.92		3.27	
Capacity (tons per kiln per day)	31.5		31.5		10.6		53.8		12.6		11.7		10.4	

[1] In producer.

[2] Under boiler.

Heat in the lime after burning: Some of this is recovered and some is lost (item 8). In plant 4 a large part of this heat is lost because the lime is drawn too hot. Most of it is recovered in the other plants—all of it in plant 1. It should be remembered, however, that there is little advantage to be gained by recovering this heat and then losing it in some other way. In plants 2, 5, and 6 it is not even put back into the kiln, but is recovered only to be lost immediately by radiation. It can be used to preheat the air either by taking the air directly through the lime, as in plants 1 and 3, or through pipes surrounding it, as in plant 5.

Heat in the stack gases: Some of this is recovered, some is used before it escapes (items 5 and 6) and some of it is lost (item 9). The only method for the recovery of this heat which was seen in operation consists of introducing some of the waste gases under the grates of the kiln according to the Eldred process (plant 2). This method is not very satisfactory from a standpoint of efficiency, because not all of the gas is used; there is a chance for loss of heat by radiation from the pipes through which the gas is conveyed, and there is no assurance that the heat recovered will be used instead of being lost again. Another method of utilization of this heat is by passing it through a boiler and generating power. At plant 1 this power is used to operate the kiln and its accompanying crushers, conveyors, etc., so that it is included in the heat used. If, however, the power were used for some purpose not directly connected with the kiln, as would necessarily be the case in the ordinary type of shaft kiln, the recovery of this heat could not be credited to the kiln, but would increase the economy of operation of the plant as a whole. In any event it could have no influence on the fuel ratio. Some of this heat might also be used to create the draft, as in plant 5, and the use of it for this purpose must be credited to the kiln. However, it is evident from the figures that natural draft requires the expenditure of more heat than any kind of mechanical draft; that is, more heat is used for this purpose in plant 5 than is necessary, which accounts in part for the observed low fuel ratio. It should also be noted that when the gas is removed by a fan it makes very little difference in the power required whether the gas is hot or cold, and that, therefore, any heat carried off by gas removed in this manner must be figured as lost and included in item 9. From the above considerations it is probable that the most efficient method of handling this gas would be to build the kiln high enough so that practically all of the heat of the gas is imparted to the stone before it leaves the kiln, and then draw the gas off by means of a fan. This method would tend to give a high efficiency and also a high fuel ratio.

It will be noted that steam is used to create the draft in plants 1, 3, 4, and 6 and that the heat used for this purpose in each of these plants is greater than in plant 2, where fans alone are used. From the data obtained the pounds of steam per pound of lime burned may be calculated as follows: Plant 1, 0.21; plant 3, 0.14; plant 4, 0.12; plant 6, 0.02. However, this steam serves other purposes besides creating the draft; it may be used to increase the capacity, lower the repair cost, or reduce the labor by keeping the grate bars free from clinkers. While, therefore, a reduction of the amount of steam used might increase the fuel ratio, it might also decrease the economy of the plant, and care should be taken to note all the effects of any change.

With good capacity and careful firing the loss of heat due to combustible in the ash should be very small; by the use of a good gas producer it should be reduced to a minimum. This seems to be the case in plants 1 and 3. The high figure shown in plant 6 can be accounted for only by assuming that the producer was pushed too hard in order to supply sufficient gas for three kilns.

The heat lost by radiation and conduction may be considered as emanating from three parts of the kiln; the gas main or fire box, the bottom of the kiln where the lime is permitted to cool after being burned, and the shaft of the kiln. A study of the designs of the various kilns shows that the following methods should tend to reduce the amount of heat lost in this manner. The gas main leading from the producer to the kiln should be short (as in plants 1 and 3) or should be insulated. The comparatively poor gas which it is necessary to use for burning lime carries a large part of its energy as sensible heat, and the loss of this heat can be prevented only by introducing the gas into the kiln at the same temperature at which it leaves the producer. Fire boxes will show less loss by radiation when built within the shell of the kiln as in plant 4, rather than externally as in plants 2 and 5. A large part of the heat contained in the lime after it is burned will be lost by radiation before the lime is drawn out of the kiln unless means are supplied by which this heat can be recovered and used, as in plants 1, 3, and 5. Unless the kiln wall is extraordinarily thin, as in plant 1, or the temperature used extraordinarily high, as in plant 5, the loss by radiation from the shaft of the kiln seems to be very small. This can be still further reduced by increasing the diameter of the kiln, as in plant 3.

In conclusion, it must be emphasized that the heat efficiency is only one item of the total plant economy. The cost of labor, the ratio of capacity to investment and the quality of the product must also be considered. Therefore, merely because the figures show plant 3 to have the highest heat efficiency would be no reason for stating that it is the most economical plant.

In light of the facts brought out by the above heat balances, a theoretical discussion of the different methods of producing the draft may not be out of place.

Natural draft, by the use of stacks, can be made sufficient to give good capacity. However, there is grave danger of overburning, for with strong draft the flame may be short and hot. Conditions may easily arise which will force the products of combustion down into the cooler, thus causing recarbonation. Since there is no means of controlling the pressure of gas over the fire, every time the fire door is opened cold air rushes in, which may cause a loss of heat and may increase the repair cost.

The practice of blowing steam under the grates is obviously one method of introducing the moisture obtained by burning wood, but water content does more than lower the calcination temperature. Part of it is undoubtedly dissociated into its elements, while passing through the hot fire. This dissociation takes up heat, which is later given out in the kiln where the elements recombine. Consequently, the use of steam tends to cool the fire and produce a larger flame, both highly desirable objects to lime burners. On account of the cooler fire and lower calcination temperature, the capacity of the kiln may be increased, with less danger of overburning than when natural draft is used. The forced draft under the grates permits of regulating the pressure above the fire, and, therefore, the fire door may be opened without admitting enough air to influence the efficiency or repair cost of the kiln. Forced draft does not, however, prohibit the products of combustion from going down into the cooler.

This danger of recarbonating the lime can be eliminated by the use of induced draft. When used alone, however, the characteristics of the fire produced by this type of draft have all the disadvantages of a normal coal fire. Since induced draft is created by a fan, any heat carried off by the waste gases is a total loss.

In many kilns a combination of forced and induced draft is used with very good results. The induced draft prevents recarbonation of the lime by removing the carbon dioxide as fast as formed. The forced draft by means of the steam jet gives a cooler fire and longer flame, and also permits control of the gas pressure over the fire. Owing to the lower calcination temperature and the greater rapidity of combustion attainable this method should give the maximum kiln capacity of the methods discussed.

Another method of combining the forced and induced draft is according to the Eldred process. The mechanical equipment for operating this process may be designed along various lines, one method being shown in Figure 10. For maximum economy the top of the kiln should be closed air tight, and all the gas should be removed by the fan, as in creating induced draft. This fan should deliver as much gas as needed under the grates, and should blow the remainder out through a stack. Separate and fairly accurate means of controlling the supply of both air and gas should be provided, and the induced draft created by the fan should be entirely independent of the amount of gas used for the forced draft. As thus installed, many advantages of the combined forced and induced draft may be obtained by using the Eldred process. The reduced draft tends to prevent recarbonation and the forced draft permits regulation of the gas pressure over the fire. The fire is kept cool by diluting the air with carbon dioxide taken from the kiln, thus causing a slower rate of

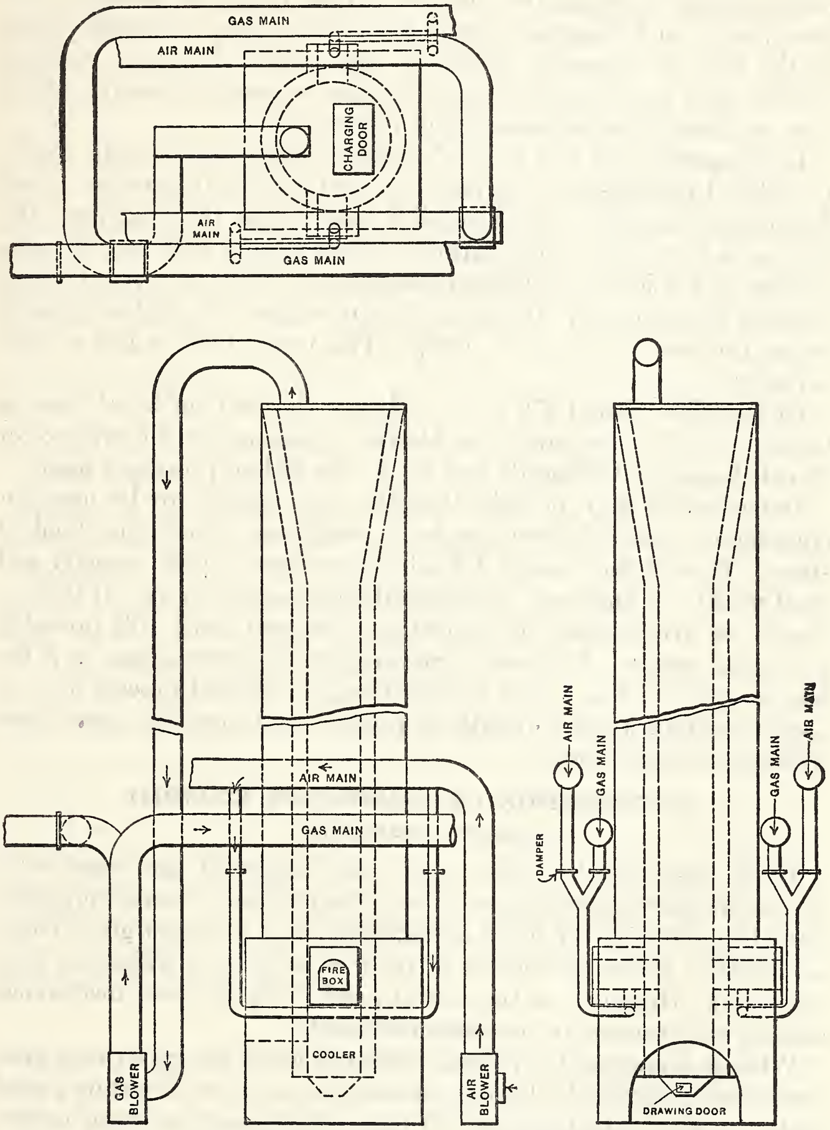

FIG. 10.—*Mechanical arrangement of Eldred process*

combustion. This carbon dioxide also aids by mechanically carrying heat from the fire into the kiln. Moreover, it may act chemically to some extent, since some of it may be reduced to carbon monoxide while passing through the hot fire. This reduction absorbs heat from the fire and liberates it again when the carbon monoxide burns in the kiln in a manner similar to the action of steam. Carbon dioxide does not serve the same purpose as steam, however, for it does not lower the temperature of calcination.

In comparing the two methods—steam and induced draft versus the Eldred process—it must be noted that they both produce a cool fire by mechanically and chemically transferring the heat from the fire box into the kiln. The former method gives a high rate of combustion and a lower calcination temperature, both of which tend to increase the capacity. Owing to lack of oxygen the Eldred process causes the coal to burn more slowly. This would tend to give a lower capacity.

Of the kilns visited 172 burn coal, and the draft of 33 of these is natural; for 25 it is forced, by blowing steam under the grates; for 73 it is forced and induced; and for 41 the Eldred process is used.

In general, it may be said that the best method to be used for creating the draft depends on local conditions, chiefly the kind of stone. Thus, if the stone is difficult to overburn, a high capacity and good quality of lime may be obtained with natural draft. If there is danger of overburning the forced and induced draft will probably give good results. If there is great danger of overburning or if the lime is apt to act as a flux in the lining, the Eldred process may be used to obtain a good quality of product and keep the repair cost within reasonable limits.

4. COMPARISON OF COMBUSTION ECONOMY

(a) DIRECT COMBUSTION

While mechanical stokers have been designed and used with success in many industries and several installations of such equipment have been tried in the firing of limekilns they have not given entire satisfaction, primarily because of the lack of firemen trained in their operation. However, as the cost of hand firing increases mechanical stoking will become an economic necessity.

What is known as the coking system of firing has given very good results wherever tried. By this method the green coal is put on a dead plate just inside the fire door, left there until coked, and then pushed back and replaced by a fresh charge. The gases distilled from the coal must pass between the fire and the arch and meet with a large amount of air coming through the burned coal at the rear of the fire box. Hence, complete combustion is practically assured. Whether this method is used or not, the economical combustion of gas coal requires that the coal be fired frequently and in small amounts.

However, this requires more labor than firing larger amounts at longer intervals, and it is a question of local conditions whether or not the saving of coal would pay for the increased labor.

The heat lost in the waste gases may be increased by two means—the admission of excess air or the incomplete combustion of the fuel. Of course, it is impossible to regulate the air to exactly the theoretical amount, and it is always better to have too much than not enough. Incomplete combustion may be caused by not having enough air, or by chilling the gases distilled from the coal below their ignition point. To prevent this latter occurrence, the arch of the fire box must be kept hot, and no more air than necessary should be admitted over the fire. In order to overcome these losses of heat the stack gases should be watched closely. If possible, the firing should be adjusted according to gas analyses. If this is not practicable the appearance of the stock gases is a fair indication of their composition. If they are perfectly colorless, it is safe to assume that too much air is being admitted; if black and smoky, the combustion will generally be found to be incomplete. The greatest economy seems to be obtained when the gases have a rather dark gray appearance.

When the fire is cleaned it is bad practice to draw it completely, since this admits a large quantity of cold air into the kiln and causes a considerable loss of heat. There is a method in use in boiler practice by which one side of a fire is cleaned at a time. This process could be used to advantage by lime burners.

In the preceding discussion of draft, stress was laid on the fact that with forced draft the pressure of the gas over the fire may be regulated. The idea in this is to use forced draft of just sufficient strength to force the air through the fire, and induced or natural draft of a strength very little more than sufficient to pull it into the kiln. By this means the pressure of the gas over the fire may be made very nearly equal to atmospheric pressure. Therefore when the fire door is opened the quantity of air admitted is very small. However, this method causes a slower rate of combustion and lowers the capacity of the kiln, unless the draft could be increased directly after firing and again checked during firing.

(b) GAS PRODUCERS

Instead of modifying the draft to make a coal fire resemble the combustion of wood, the coal itself may be modified by converting it into producer gas. The claim for the greater economy of gas producers is based on the lower labor cost and the greater convenience and adaptability of the gas. By adaptability is meant that the fire can be placed where wanted. This is especially important in limekilns, where coal must be burned in external fire boxes, while the gas can be introduced directly into the kiln itself.

Practically all producers generate mixed gas, consisting of the products of distillation, carbon monoxide, and water gas. Air is blown through the bed of coal by a steam jet. In such producers, the heat of the coal is used up in four ways; namely, the reduction of the carbon dioxide formed to carbon monoxide, the decomposition of the steam, the distillation of the hydrocarbons from the coal, and raising the temperature of the gas. When the gas is burned the hydrogen and carbon monoxide liberate the exact amount of heat taken up by their formation. This, together with the heat generated by combustion of the hydrocarbons, may be called the "potential" heat of the gas. It is evident from the definition that a gas must have practically the same potential heat at the kiln that it had when leaving the producer, but the amount of sensible heat retained depends entirely on the chances for loss by radiation. Therefore it is imperative to have the producer as near the kiln as possible, and to have all gas mains well insulated. Of course, the higher the proportion of noncombustibles in the gas the greater will be the sensible heat in proportion to the potential heat and the more carefully must loss be guarded against. In limekiln practice it has been found that a rich gas (one high in combustibles) gives too hot a fire with too great danger of overburning the lime. Therefore a gas with a large proportion of noncombustibles should be used, and care should be taken to prevent the loss of sensible heat. Another reason for keeping the gas hot is to prevent condensation of the hydrocarbons. These have a high heating value, and the loss of even a small amount of them should not be permitted. It is evident that if the gas is kept hot enough to prevent condensation of the hydrocarbons the potential heat is independent of the temperature; also if the gas enters the kiln at the same temperature at which it leaves the producer the loss of sensible heat will be zero. It should be possible, therefore, to design a plant so that the use of a poor gas instead of a rich one should make practically no difference in the efficiency of transmission of heat from producer to kiln.

It is customary to mix the gas with air just as it enters the kiln, thus producing combustion in direct contact with the stone. The gas is blown in by forced draft, and steam is one of the chief products of combustion. These considerations indicate that in a gas-fired kiln it should be possible to force the flame farther toward the center, the burning zone should be longer, and the calcination temperature should be lower. Consequently, the kiln should have a larger capacity and should produce a better quality of lime. For a large plant the labor cost should be less. There is, however, the danger of recarbonation, which occurs wherever forced draft alone is used. Care must be taken not to blow in the gas and air so fast that the products of combustion, containing carbon dioxide, will have any tendency to go down into the cooler.

Gas producers have one decided advantage over methods of direct firing, as a much cheaper fuel may be used, and while the coal must be low in sulphur content to prevent corrosion of the iron and contamination of the lime it may be higher in ash and have a lower heating value than the grade of coal most economical for direct firing.

Producers may be obtained which are supplied with a device for automatically and continuously feeding the coal and removing the ashes. The fuel bed revolves, so that its depth is kept uniform. Such a producer would cost more to install than the types generally used and would require a small amount of power for its operation. These economic difficulties may be more than counterbalanced by the saving in labor and the production of a uniform quality and pressure of gas. This last point is of especial importance to lime manufacturers.

If the plant is properly designed, with especial regard to preventing any loss of heat by radiation, and is run by a competent foreman, so that the gas is not too rich, is not blown in too fast, and is mixed with very nearly the theoretical amount of air, the use of a gas producer should prove at least as economical as any method of direct firing of coal.

V. PROCESS OF MANUFACTURE OF HYDRATED LIME

The manufacture of hydrated lime on a commercial scale had its inception about 1900 and consisted essentially of slaking the lump lime to a wet paste after which the excess moisture was expelled and the dry product ground. However, the excessive cost of manufacturing by this process led to its early abandonment. More modern methods of manufacture have proved so successful that in 1925 the production of hydrated lime amounted to in excess of 1,500,000 tons.

In the manufacture of hydrated lime the following stages must be considered, starting with the burnt lime as it comes from the kilns: Crushing, hydrating, screening, and packing.

The object of crushing the product is to produce a larger surface for the action of the water, and, moreover, large lumps would be rather unwieldly in the hydrator.

After crushing, the lime is fed into the hydrator. Here it is mixed with the correct amount of water and agitated until the reaction is complete.

It comes from the hydrator as a fine, dry powder, which must be classified either by screens or air separators to remove any core or overburned lime that would not slake.

From the screens or separators it goes to the storage bins, where, if the capacity is available, it is deemed advisable to let it age for 30 days. Aging is not of particular importance if sufficient care has been used during the hydration.

Finally, it is fed into the packing machine which puts it into bags for shipment.

The equipment generally includes 2 elevators, 1 to take the lime from the crusher to the bin over the hydrator, and 1 to take the hydrated lime from the hydrator to the storage bin.

Most mills also include a machine for grinding the tailings from the screens or air separators. This material consists of unburned stone, overburned lime, lime which is not completely hydrated, and even pieces of brick and coal ashes. When ground it can be sold as fertilizer, but certainly should never be called hydrated lime.

1. CRUSHING THE LIME

One reason for crushing the lime is that it will lessen the time of slaking and increase the capacity of the hydrator. It is obvious that the less porous is a lime and the more magnesia it contains the more finely should it be crushed.

Another reason for crushing the lime is that large lumps would be unwieldy in the hydrator. In this the lime and water must be agitated with some form of paddle. By using small pieces of lime a thorough mixture can be obtained more easily, and it is also easier to determine when sufficient water has been added. Furthermore, there is experimental evidence [24] which indicates that if the quicklime is finely ground before hydration the properties of the hydrated product will be materially improved.

Where shaft kilns are used a gyratory crusher is generally employed for crushing the lime. There is no reason for preferring this machine to others except that it can be obtained in various sizes to suit the requirements of the plant. The size of the crushed lime at most plants is about 1 inch, although in some cases it is crushed as fine as to pass a No. 10 sieve.

2. HYDRATORS

The actual slaking of the lime takes place in an apparatus called the hydrator. Theoretically, the only function it has to perform is to mix the lime and water thoroughly and quickly, to prevent burning the lime by local overheating. Just what happens when lime "burns" during slaking is not very well understood. If a lump of lime is given enough water to start hydration but not enough to complete the process, the unslaked portion will "burn" and become

---

[24] "The effect of particle size in the hydration of lime," by F. W. Adams, J. Ind. and Eng. Chem., May, 1927.

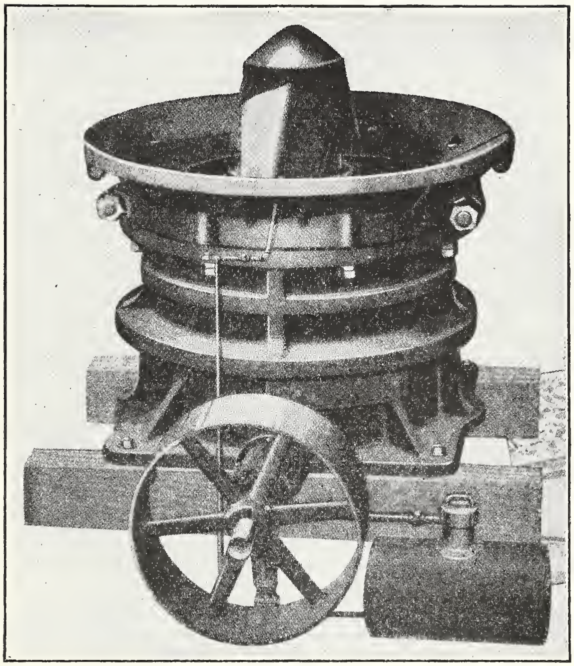

Fig. 11.—*Gyratory crusher used for crushing lime*

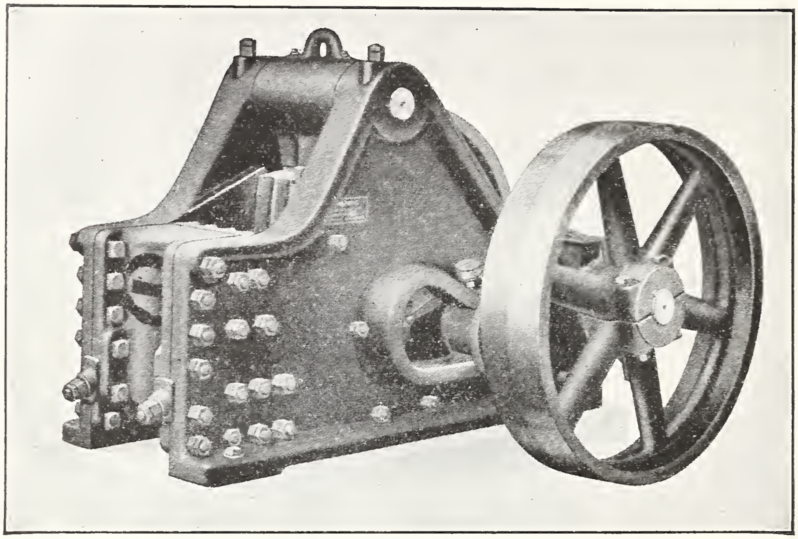

FIG. 12.—*Type of jaw crusher used for crushing lime*

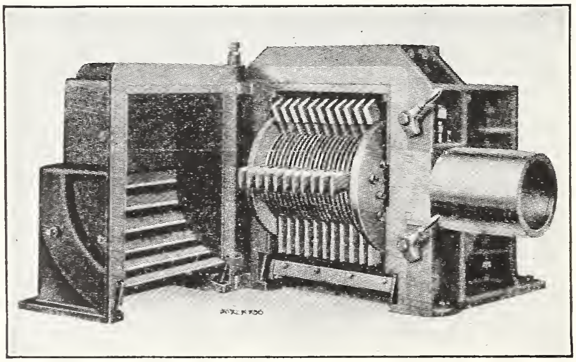

FIG. 13.—*Hammer mill*

practically useless. This phenomenon is probably due to some change in the physical condition of the lime caused by the concentrated heat. It is, therefore, absolutely necessary that sufficient water be added and that it shall be mixed with the lime very thoroughly and quickly. It has been noted that because of the slow slaking of magnesian limes, difficulties due to "burning during hydration" are not of serious importance. In fact, insufficient hydration is a more common trouble.

Of the 16 hydrate plants visited, 7 are equipped with Clyde hydrators, 3 with modifications of this machine, 2 with Kritzer hydrators, 2 with Schaffer hydrators, 2 with Carson hydrators, and 1 with a modified Kritzer hydrator.

The Clyde hydrator differs essentially from the Carson, Schaffer, and Kritzer in that it is intermittent in operation while the others are continuous. The fact that the Clyde was the first on the market, and is capable of producing an excellent grade of hydrate, accounts for its widespread and numerous installations.

The Clyde hydrator consists of a circular iron pan large enough to hold about 1½ tons of hydrated lime, and capable of revolving horizontally. Suspended in the center of this pan is a fixed shaft with arms radiating from its lower end. These arms carry plows, which scrape the bottom of the pan, and are arranged in a horizontal spiral so that every part of the pan is touched at least once each revolution. The whole machine is surmounted by a hood and stack to carry the dust out of the building.

In operating a Clyde hydrator, the pan is first started revolving. A definite amount of crushed lime is then fed in, generally from an automatic weighing bin. Then the water is turned on. The amount of water used is sometimes regulated automatically by an overflow tank or some such arrangement, but more often it is left to the discretion of the man in charge. If the man is a good operator, the latter method is probably to be preferred. A large proportion of the water added is given off as steam, and the amount of this generated depends on whether the room is warm or cool, and to what extent the machine has been heated by previous charges. Therefore, the quantity of water is not constant and requires supervision. After the water has been added, the pan is kept rotating until hydration is complete. This requires from 6 to 20 minutes, depending on the quality of lime used. The end of the reaction can be readily discerned with practice. The powder becomes very light and appears dry, and the evolution of steam ceases. A central section of the bottom of the pan is then raised and the plows force the product through this opening into the bin below.

The Kritzer hydrator consists of a series of long iron tubes, arranged horizontally one above the other to save space. Within each tube is a screw conveyor which carries the lime through it. The lime is admitted at one end of the upper tube. At the end through which the lime enters is a large vertical stack. The water is admitted about two-thirds of the way up this stack, and falls down it over a series of baffle plates into the pipe. Here it meets the lime. The two substances are mixed very thoroughly by the screw conveyor, and at the same time are carried through the tube. The conveyors are run at such speeds that when the mixture has reached the end of the series of tubes, hydration is complete. In this machine it is impossible to regulate the quantity of water automatically, on account of the constantly increasing temperature (and consequent evaporation) when it is running.

The Schaffer hydrator, while somewhat resembling the Clyde in operation, differs, in that it is continuous. The crushed quicklime is delivered to the hydrator at a definite rate, usually by means of an automatic weighing device. The feeding device is so arranged as to seal the entrance passage, preventing the escape of steam. The hydrator is divided into several sections, each section being provided with a revolving disk and a stationary disk. The lime is fed on to the uppermost disk, together with the hydrating water. The mass is thoroughly mixed by means of plows and passes over a rim on the periphery of the disk to the one underneath which is stationary. The lime falling on to this disk is directed by moving plows attached to the upper disk to an opening in the center where the lime falls to the next disk below which rotates. This process is repeated in each section until the lime is finally deposited into a screw conveyor at the bottom of the hydrator. Two stacks to which are attached water tanks of a definite capacity for hydrating a certain amount of lime and which are emptied automatically by the lime measuring mechanism, surmount the hydrator. By virtue of the positions of the tanks the water is warmed by the hot air passing up the stacks.

In the upper portion of the hydrator the steam and water pass downward with the lime, while in the lower section air for cooling and drying the hydrate passes upward in opposition to the lime. Baffles are located in such positions as to catch the dust and moisture, which are returned to the hydrating chamber. A line drawing of this type hydrator is given in Figure 16.

The Carson hydrator, or more properly the Carson system, consists essentially of a pug mill hydrating unit and storage bins. The crushed lime is fed into the pug mill at a uniform rate and the hydrating water is added to the lime at the receiving end of the pug mill. The amount added is left to the discretion of an experienced operator, who judges the condition of the hydrate by its appearance at the discharge end of the pug mill. From the pug mill the hydrate is conveyed to storage silos where the hydration is completed. It is drawn from the silos after about 48 hours. This process is extremely

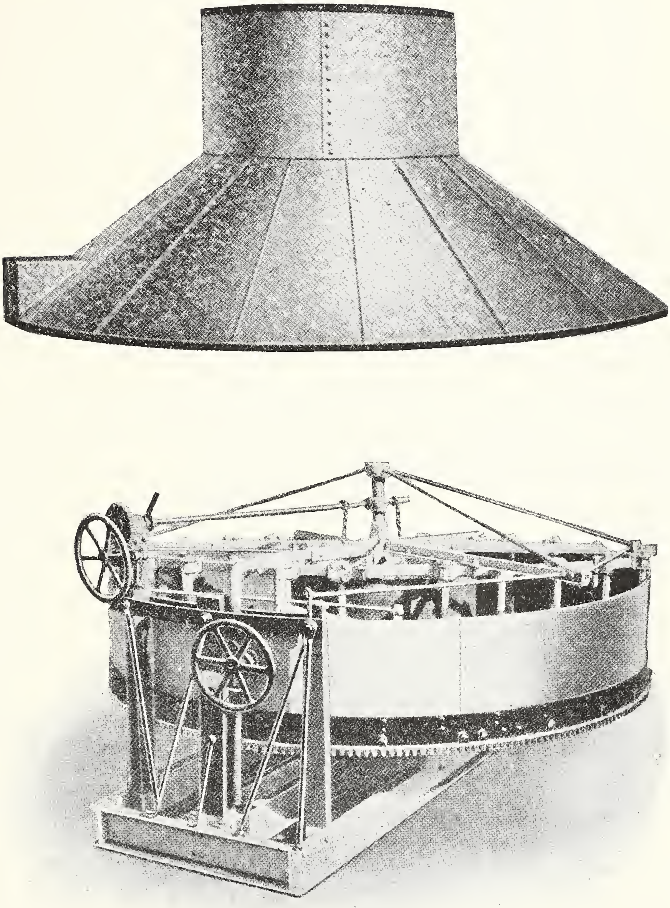

Fig. 14.—*Clyde hydrator with dust hood*

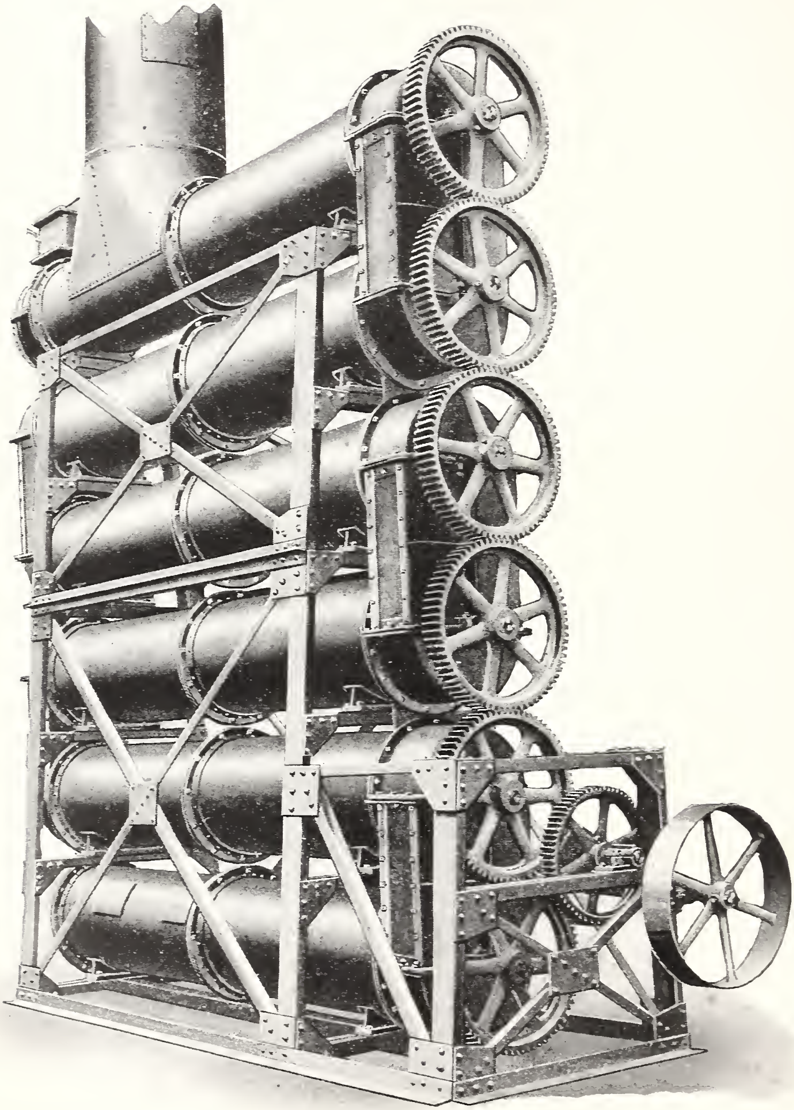

FIG. 15.—*Kritzer hydrator*

simple, and in certain installations an excellent grade of hydrate is produced. The success of the method depends on the ability of the control man and the properties of the lime, but, inasmuch as the latter is true to a great extent in all hydration processes, it should not be considered applicable to the Carson process alone.

One of the modifications of the Clyde hydrator is an ingenious adaptation by which a more thorough mixing is accomplished. The pan revolves as in the ordinary machine; the shaft carrying the plows revolves in the opposite direction and each plow is replaced by a screw propeller, which also revolves on its own axis. A second modification is the installation, after the hydration process, of a scraper conveyor which allows the lime to cool somewhat before going to storage. A third modification to lessen the danger of burning during hydration consists merely in using a smaller machine and less lime.

In general, magnesian limes hydrate far less quickly than high calcium limes, and there is less danger of "burning."

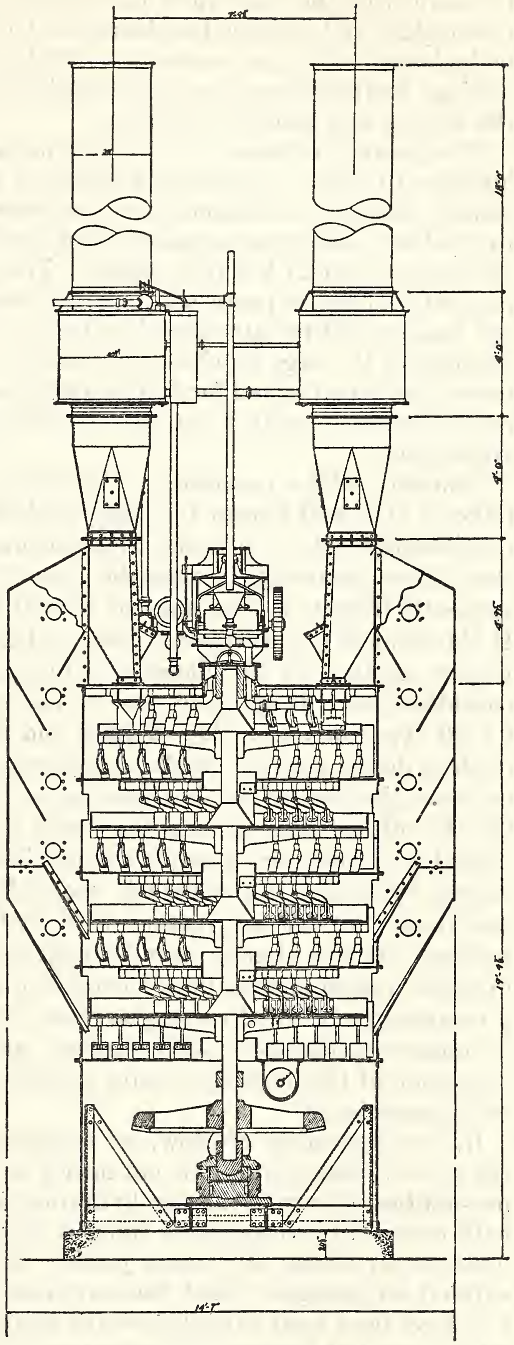

Fig. 16.—*Schaffer hydrator*

Consequently, the water does not need to be mixed so quickly or so thoroughly, and practice has demonstrated that magnesian limes can be hydrated with good success in a Clyde hydrator. Excellent high-calcium hydrate from very quick-slaking lime is now being made by the Kritzer and Schaffer machines.

The quantity of water to be used in making hydrated lime is a very important factor. As indicated above, it must be varied to suit constantly changing conditions, and considerable experience is required to be able to tell by the appearance of the finished product just when the correct amount has been added. Too much water will cause the product to become pasty and clog the screens. If too little is used the balance will be later absorbed from the air, with the consequent bursting of the bags in which it is stored. As yet no rapid practical means has been devised for determining the quantity of water present in the finished product, so that it must be judged merely by its appearance.

Summary.—The essentials of hydration may be summarized as follows: It is well known that the rapidity of slaking of limes varies considerably. As a rule the high-calcium limes slake much faster than those containing appreciable quantities of magnesia and consequently liberate a large amount of heat in a short interval of time. If this heat is not dissipated there is danger of burning, with deleterious results. In the choice of a hydrator these points should be considered, as it is apparent that no one type of hydrator is suitable for all types of lime. The Kritzer and Schaffer hydrators because of their design provide ample cooling surface, but are built so as to conserve the heat of the hot gases in warming the hydrating water. On the other hand, because the water is heated and fed into the hydrator at one point there is the possibility of burning of the lime during hydration if the lime is especially fast slaking. However, this danger is not so great as with hydrators having less cooling surface. As has already been stated, such hydrators as the Clyde, in which a large mass of lime is contained in a receptacle so that only a comparatively small cooling surface obtains, have been employed in numerous instances with success, probably because of proper regulation of the hydrating water so that the excess heat is absorbed by evaporation.

In the hydration of slow, or comparatively slow slaking limes the area of cooling surface is not nearly as important a factor and the possibilities of burning during hydration are not as great. In fact, with excessively slow-slaking limes it may be necessary to heat the hydrator by means of a steam jacket. Hot water may also be used without any danger. Both the continuous and batch process hydrators have been used with success for hydrating magnesian and dolomitic limes, but because of the slowness of hydration in some instances it is customary to store such hydrated products in bins or silos for some hours or even days to allow the process to be completed.

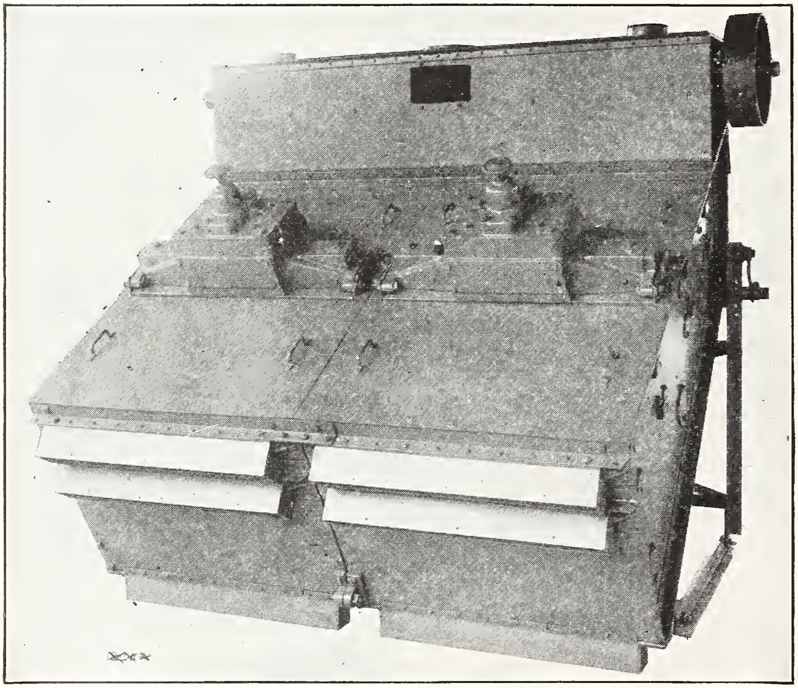

FIG. 17.—*Six-foot, two surface, electric, vibrating screen, inclosed, with screw-feed distributer*

3. SCREENS AND AIR SEPARATORS

The hydration of lime is accompanied by an increase in volume, which causes the lumps to disintegrate. Evidently anything which does not hydrate will retain its original lump form and can be separated from the hydrated lime by either screening or air separation.

The Jeffreys screen, which is used in the majority of plants visited using screens, consists of a wooden frame with wires stretching across the bottom. One end of the screen is higher than the other. The material from the hydrator is fed in at the upper end and caused to slide down over the wires by giving the screen and framework a shaking motion. The hydrated lime falls through, while the impurities pass on. The wires are set usually to form a "36 diagonal mesh"; that is, there are 36 spaces between wires per linear inch, and the wires are set diagonally so that the squares formed by their intersections have their diagonals lengthwise of the screen. It has been found that this method of construction produces the same effect as a much finer mesh with the wires set straight. Consequently, heavier wires can be used, with less danger of breaking. The whole apparatus is covered to keep in the dust.

The Newaygo screen, another type commonly employed, is very similar to the Jeffreys. The chief difference is that the frame of the former is of iron instead of wood. It is claimed that a wooden frame will warp, thus distorting the wires and forming cracks through which dust escapes. For these reasons the iron frame is to be preferred.

Another type of screen, commonly called the "knocker," is quite extensively used. It differs from the "shaker" type only in the manner of vibration.

Experience and investigative work[25] have shown that material which passes a "36 diagonal" screen is not suitable for many uses to which hydrate is put. Especially is this true of hydrate for certain chemical uses and of the hydrate employed in the finish coat of plaster work. For these reasons, and also because cold hydrate (especially when containing a slight excess of water) tends to ball together, the use of air separators is coming more and more into prominence. Several types are used, probably the most common being the Raymond impact mill and the Raymond roller mill. In the impact mill the coarse particles are separated out while in the roller mill they are ground up and blown off with the hydrate.

An air separator consists essentially of a rotary fan. The substance to be separated is mixed with the air taken into the fan. When the air is discharged the lighter particles are carried with it, while the heavier ones settle out. The air is blown into a suitable chamber

---

[25] The Effect of Certain Materials in the Finish Coat of Plaster, J. M. Porter, Proc. A. S. T. M., 1: 1926.

where its velocity is so much reduced that the finer particles are deposited. The same air can be used over again, so that the system can be kept tight and the spreading of dust prevented.

Air separators have several advantages over screens. They are practically dust proof, a factor the importance of which can not be overlooked. A variation in the size of the particles taken out can be made by merely changing the speed of the fan, whereas a screen can be used for one size only. However, provision must be made to operate the fan at a constant speed which has been found suitable for the desired sizing.

4. ELEVATORS, BINS, AND PACKERS

Two elevators are generally used in a hydrate mill, one to take the lime from the crusher to the hydrator, and one to take the hydrated lime from the hydrator to the screens or air separator. If the tailings are ground and rescreened, another elevator is required to take them from the grinding machine to the screens. These elevators are almost exclusively of the bucket type, inclosed within a tight shell of wood or metal. Every precaution should be taken to make the inclosing shell tight, to prevent leakage of dust. If of wood, a good method of constructing the shell is to build it of two thicknesses of matched lumber with a layer of canvas between them.

Where hydrated lime is to be transported horizontally, a screw conveyor is generally used. It is easily kept tight and dust proof and affords further opportunity for mixing the product.

From the screens or air separator the hydrated lime goes directly to the storage bin, where it may be aged or not, depending on the kind of lime and the size of the plant. These bins are generally built of wood, steel, or concrete, and here, also, precautions must be taken to make them dust proof. Hydrated lime, especially if a little moist, is apt to be sticky and will not flow. Consequently, the bins must have steep sides and rather large openings.

The packer is the machine which takes the product from the bins and packs it in bags. Hydrated lime is shipped in paper bags of 40 or 50 pounds capacity.

Twelve of the thirteen plants visited used Urschel-Bates patent valve bagging machines. This machine consists of a long, narrow, horizontal wooden box in which is revolved a shaft with pins projecting from it. The hydrated lime flows from the bin into the box. The pins convey it along the box and keep it stirred up to prevent its sticking. Along the bottom of the box are several openings which may be closed by means of a lever and which, when open, connect with a long muffle-shaped chute. The bag to be filled is connected to the chute and the lever is raised so that the hydrated lime flows in. The bag rests on a scale pan, counterbalanced by a weight. When this weight of hydrate has been admitted, the scale pan drops, and in so doing pulls down the lever, thus closing the opening in the box and stopping the flow of hydrated lime. The Urschel-Bates valve bag is so made that both of its ends resemble the bottom of an ordinary bag. In forming the ends the smaller sides are folded over first and are overlapped by the larger sides. One of the smaller sides is left unfastened and through this opening the muffle-shaped chute is inserted. When the bag is filled, the pressure of its contents forces the smaller sides against the overlapping portions of the larger sides and thus closes the bag. When made of paper such a bag can not be opened without tearing. If cloth is used, the top is made open in the usual manner and is tied before filling. The bag is then filled through a valve in the bottom.

Hydrated lime is a very fine powder, which will rise up in clouds of dust and permeate the air at every opportunity. On account of its caustic properties it is a very disagreeable substance to breathe. Hence, every precaution must be taken to make all machinery dust proof or the labor problem will become very difficult. The Urschel-Bates valve bag gives much less opportunity for the dust to get out than a bag which is filled while still open and which must be handled and tied after filling.

5. TAILINGS

What to do with the tailings from the screens or impact mill is a very perplexing question. One manufacturer has found that his tailings consist chiefly of partially hydrated lime. He exposes them to the action of the steam generated in the hydrator and then returns them to the screens. Once a day the conveyor is opened, and what little refuse has accumulated is taken out and thrown away.

Another manufacturer has found that his tailings are mainly silicates and aluminates of calcium. At the time of the writer's visit he was investigating the possibilities of fine grinding and the addition of hydrate for the production of a hydraulic lime. At another plant the tailings are sold for fertilizer.

All of the other plants visited find it necessary to grind the tailings, after which they are put back on the screens and mixed with the material coming from the hydrator or are blown along with the fine hydrate if a roller mill with an air separator is employed. The product so obtained is sometimes sold for fertilizer and sometimes as first-quality hydrated lime. This latter practice is certainly to be condemned. It nullifies the most important function of screens, if used, and impairs the quality of an otherwise good product.

The tailings are generally rather soft and in small pieces, so that almost any machine may be used for grinding them. The machines seen in operation were: Jeffreys mill, Kent mill, Fuller-Lehigh mill, Sturtevant rock-emery mill, Sturtevant pulverizer, Raymond roller mill, and Williams crusher.

VI. CHARACTERISTICS OF LIME FOR VARIOUS USES

The latest available figures (1925) of the Bureau of Mines relative to the uses of hydrated lime and quicklime indicate that the building and chemical industries are the largest consumers of these products, the former taking 52.1 per cent of the total produced and the latter 41.4 per cent. The remaining 6.5 per cent was sold for agricultural purposes and will not be considered in the discussion which follows.

Unquestionably the major portion of the lime employed in construction work is quicklime, but the use of hydrated lime is rapidly increasing. Three main subdivisions of the uses of lime in construction may be made (1) in plaster, (2) in mortar, (3) in concrete.

Hydrated lime for use in plaster, according to the specifications of the American Society for Testing Materials,[26] should contain not less than 95 per cent of calcium and magnesium oxides, computed on the nonvolatile basis, nor more than 7 per cent of carbon dioxide, on the same basis. Furthermore, it should not leave a residue of more than 0.5 per cent on a No. 30 sieve or 15 per cent on a No. 200 sieve, nor contain a sufficient quantity of materials to cause expansion or disintegration of a test specimen. If the hydrate is to be used for finish coat work it should, in addition to meeting the above requirements, be highly plastic; that is, it should spread easily under the trowel of the plasterer after being hydrated properly.

The requirements of quicklime for plastering are quite similar to those for hydrated lime.[27] The calcium and magnesium oxides should not be less than 95 per cent; the carbon dioxide should not exceed 10 per cent, and when slaked the residue on a No. 20 sieve should not be greater than 15 per cent. Furthermore, the silicon, iron, and aluminum oxides should be less than 5 per cent.

Lime for stucco and mortar work should meet the same requirements as for plastering. It is used in the preparation of "straight" lime or lime-cement mortars and stuccoes.

In view of the discussion given in Section II, 1 and 2, it is not necessary to enumerate the reasons for the requirements in the above-mentioned specifications.

Lime is employed as an admixture to concrete to improve the "workability," resulting in less effort being necessary for the placement of the wet mix. Other claims which can not be easily demonstrated, such as diminution of porosity and improvement in appearance, are also made for concrete containing lime. For such purposes hydrated lime is usually employed. The composition of lime most suitable for addition to concrete has not been thoroughly investigated, but there seems to be no basis for the assertion that

---

[26] Standard Specification for Hydrated Lime for Structural Purposes (Ser. Desig. C6–24).

[27] Standard Specification for Quicklime for Structural Purposes (Ser. Desig. C5–26).

lime high in magnesia will give trouble. Obviously lime for this purpose should be thoroughly hydrated before being mixed with the concrete.

In the chemical industries about one and nine-tenths million tons of lime were used in 1925, distributed as follows:

	Short tons
Glass works	73, 011
Paper mills	376, 670
Insecticides	14, 019
Sand-lime brick	25, 144
Sugar refineries	19, 089
Silica brick	25, 901
Water purification	115, 776
Tanneries	62, 933
Ammonia distillation	28, 999
Soap	16, 008
Metallurgy	411, 190
Refractory (dead-burned dolomite)	392, 147
Other uses	333, 693
Total	1, 894, 580

The Interdepartmental Conference on Chemical Lime, composed of representatives of the various Government bureaus and agencies dealing with lime, with the cooperation of lime manufacturers and users, has drafted recommended specifications for lime for a number of chemical uses. In certain instances specifications have not been prepared because of lack of definite information or because it was the opinion of the conference that specifications would be useless, if not harmful.

The specifications prepared by this conference have been used largely as the basis for the following general discussion of the various uses for lime.

Glass.—The most common glasses are fused mixtures of alkali (usually soda), alkaline earth (usually lime), and silica. Freedom from color is an important property of glass. This property is dependent upon the absence of coloring oxides (usually iron) in the raw materials. Limestone, quicklime, or hydrated lime may be employed, and the choice is generally based on availability, cost and present practice.

The quality of the lime used may vary. Any lime passing a No. 16 sieve and containing more than 83 per cent of the oxides of calcium and magnesium is suitable for glass manufacture, provided the iron oxide does not exceed 0.8 per cent; the sulphuric and phosphoric anhydrides, 1 per cent; the silica, 17 per cent; and the alumina, 5 per cent. The composition should not vary from day to day more than 2 per cent.

Paper.—In the manufacture of paper, lime may be used in three different ways, depending on the process: If old rags or other textile materials are utilized for the making of paper the first step in the process is to cook the rags with lime, soda ash, or caustic soda, or a mixture of soda ash and lime in a digester under steam pressure. After this treatment they are washed to eliminate as much noncellulose material as possible. Either quicklime or hydrated lime may be employed, depending upon its availability, cost, and present practice of the mill. If quicklime is used it should contain not less than 95 per cent calcium oxide; and hydrated lime not less than 72 per cent. The magnesium oxide, other oxides or insoluble matter, or carbon dioxide should not exceed 2 per cent for quicklime or 1.6 per cent for hydrated lime.

When wood of coniferous trees, such as pine, hemlock, etc., is used for making paper pulp it is boiled under pressure with calcium bisulphite ($Ca(HSO_3)_2$). The latter is made by passing sulphur dioxide up a tower containing limestone or by bubbling the gas through milk of lime contained in tanks. For the last-mentioned process quicklime, high in magnesia, is used. Magnesium salts are more soluble than calcium salts and consequently the latter have a tendency to clog the system. However, due to variations in tank systems, it is probable that high calcium lime would give good results in certain instances. Regardless of the kind of lime employed the oxides of silicon, iron, and aluminum should not exceed 3 per cent.

If wood of deciduous trees, such as poplar, cottonwood, etc., is employed it is boiled with soda at a pressure of about 90 pounds per square inch. The cooking liquor and the pulp are separated and the latter washed with clear water until free of soda. The liquor and washings are evaporated and the residue calcined. In the calcination the organic matter is burned off and the soda ash recovered, after which it is recausticized by lime. Quicklime is usually employed and should contain not less than 85 per cent "available lime" as determined by the modified Saciffe method. Lime containing more than 70 and less than 85 per cent "available lime" may be employed, but the efficiency of the process is diminished. Lime containing more than 3 per cent magnesia and less than 70 per cent "available lime" is uneconomical to use.

Insecticides, etc.—Lime is used in the preparation of a number of insecticides, fungicides, and disinfectants. Several of the more important include calcium arsenate, lead arsenate, Bordeaux mixture, and Paris green.

The manufacture of calcium arsenate requires probably more lime than does the manufacture of any other insecticide, etc. The method most commonly used in the making of calcium arsenate consists in the addition of a solution of arsenic acid to a suspension of calcium hydroxide in water, under controlled conditions designed to give a product having certain desired chemical and physical properties. The calcium hydroxide suspension is usually prepared immediately before use by the slaking of lump quicklime, but hydrated lime is sometimes used. The lime should be slow settling, high in calcium, and contain not more than 2 per cent of magnesia. It should also be relatively free from carbonates and inert substances.

Sand-lime brick.—In the manufacture of sand-lime brick a small percentage (about 10) of lime is mixed with sand and the mix dampened and molded into shape by pressure, after which the bricks are steamed for several hours with a steam pressure of about 130 pounds. This latter treatment causes a chemical reaction to occur between the sand and lime, with the formation of what is believed to be a hydrated calcium silicate which acts as a binding material for the excess sand. The lime should be completely hydrated before it is mixed with the sand and made into brick because subsequent hydration is apt to weaken or disrupt the brick. Overburned lime and magnesia also may cause trouble on account of their slow hydration. The lime should contain not less than 85 per cent calcium oxide nor more than 5 per cent magnesium oxide, both figures being based upon the nonvolatile portion of the material. Furthermore, the quicklime should slake readily and completely and be free of such visible impurities as ashes, clinker, and fused silicates.

Sugar.—In the sugar industry lime is used either to precipitate impurities from the juices or sirups or, in the Steffen process, to precipitate the sugar from impure solutions. For the former purpose either lump quicklime or hydrated lime may be used; for the latter purpose very finely ground quicklime, known as lime powder, is required. When the process requires the addition to the juice of an excess of lime which is afterward precipitated by carbon dioxide, the sugar manufacturer usually finds it economical to buy lime and carbon dioxide together in the form of limestone, burning the latter at the sugar plant to produce the lime and CO_2. Only high calcium lime is satisfactory in the sugar-making processes, and the quicklime, hydrated lime, or stone from which they are made should be not less than 85 per cent pure for the treatment of the juices or sirups; in the Steffen process lime powder must contain 90 per cent sugar soluble lime, and the quicklime or limestone used in making it must be correspondingly pure. Furthermore, the lime powder should be relatively free of moisture and overburned lime and of such fineness that 98 per cent will pass a No. 200 sieve. Sulphates and soluble silica are also objectionable materials in lime used in sugar production.

Silica brick.—In the manufacture of silica brick, silica, preferably quartzite, is ground in a wet pan until the particles are of suitable size. Milk of lime is then added in quantities varying from 1.5 to 4 per cent calcium oxide (based on the weight of the silica) and the shapes are molded and dried. When bone dry they are burned until most of the quartzite has been converted into tridymite and christobalite. In the process either quicklime or hydrated lime may be used. The lime should be comparatively free from ash, dirt, and core, and the fineness of the hydrate and rapidity of slaking are desirable properties. When based upon the nonvolatile portion of the quicklime or hydrated lime the calcium oxide content should be not less than 92 per cent; the magnesium oxide should not exceed 3 per cent; and the combined iron and aluminum oxides (Fe_2O_3 and Al_2O_3), together with the silica (SiO_2) and insoluble matter, should not be greater than 4.5 per cent. Furthermore, the carbon dioxide (CO_2) should not exceed 5 per cent if the sample is taken at the place of manufacture or 10 per cent if the sample is taken at other than the place of manufacture.

Water purification.—In the treatment of water for public supplies lime is used alone or with iron sulphate or aluminum sulphate to produce a precipitate which assists in the clarification of the water and in the removal of bacteria by filtration. Lime and soda ash are used together for softening water and lime is sometimes used alone to partially soften water.

Quicklime is frequently used in municipal purification plants, while smaller softening plants usually employ hydrated lime.

High calcium lime is the most satisfactory for use in the purification of water and the recommended specification of the Interdepartmental Conference on Chemical Lime suggests that a penalty or a premium apply to quicklime containing less or more than 90 per cent "available" lime and that the standard of composition for hydrated lime should be 90 per cent "available" calcium hydroxide. As underburned and overburned lime retard the slaking process their presence is objectionable.

Leather.—After the softening and cleansing of hide or skin is completed it is immersed in a milk-of-lime suspension, or a milk-of-lime suspension to which other materials have been added. The purpose of this lime treatment is to swell and soften the epidermal cells and dissolve the mucous layer, thereby loosening the hair so that it may be removed easily. Either quicklime or hydrated lime may be used and should be high in calcium except in the manufacture of Morocco leather where a high magnesium lime is permissible.

The quicklime should contain not less than 90 per cent "available" lime and the hydrated lime not less than 85 per cent "available" calcium hydroxide. Neither the quicklime nor hydrated lime should contain more than 1.5 per cent iron oxide and if to be used in the manufacture of white leather the iron oxide content should not exceed 0.15 per cent. In addition, the lime should be substantially free from ash, dirt, and core. Fineness of the hydrate and slow settling of the suspension are also desirable properties.

Soap.—Lime is used for neutralization of glycerine sweetwaters in the soap-making process and in the causticizing operation. The glycerine water is obtained by steaming the mass of melted and purified fat with 1 per cent of sulphuric acid. After settling, the glycerine water is drawn off, neutralized with lime and evaporated to crude glycerine. The residue of fatty acids is again neutralized with lime to remove all soluble acids before the fatty acids are stored for later use in soap making.

In the causticizing operation lime is added to solutions containing alkali carbonates for the purpose of forming the corresponding hydroxides, or caustic alkalies. These latter materials remain in solution, while calcium carbonate is precipitated. The solution and precipitate are separated; the solution is concentrated by evaporation to the extent desired for the object in view and the calcium carbonate sludge is either converted into lime or discarded.

For neutralization of glycerine water lime should be free from grit to prevent undue wear on pump linings. Magnesium compounds tend to form scale formations in evaporation tubes, consequently a high calcium lime is desirable. In the causticizing, impurities ordinarily found in lime, as well as underburned and overburned lime, retard the slaking process. They also increase the volume of the sludge, which then either requires more time in washing or carries off more inclosed caustic alkali. Magnesium compounds do not settle either quickly or well in a solution of caustic. Therefore a high calcium lime is more suitable for both the neutralization of glycerine sweetwaters and the causticizing process.

Quicklime for use in soap making should contain not less than 90 per cent "available" lime, and hydrated lime should contain not less than the same amount of "available" calcium hydroxide. Neither should contain more than 3 per cent magnesia or 1 per cent insoluble matter.

Ammonia distillation.—In the distillation of ammonia liquors obtained in coke and gas manufacture lime is used in two ways: (1) In the concentration of crude ammonia liquors at gas plants or by-product coke-oven plants for the production of concentrated liquors for shipment to chemical factories and (2) for the distillation of concentrated ammonia liquors to produce aqua ammonia, anhydrous ammonia, or ammonium salts. Quicklime and hydrated lime are used, the latter to a limited extent only. High calcium lime is most effective for the distillation of ammonia except in a few instances where, because of especial type equipment, a magnesian lime may be satisfactory. The presence of inert material and underburned and overburned lime are objectionable inasmuch as they retard the slaking process which introduces delays and reduces the efficiency of the equipment. The quicklime should slake readily when immersed in water and disintegrate into a suspension of finely divided material. A content of 92 per cent "available" calcium oxide and "available" calcium hydroxide, for quicklime and hydrated lime, respectively, has been recommended with the suggestion that a premium or penalty be applicable to lime above or below this value.

Steel.—Quicklime is used in the basic Bessemer and basic open-hearth processes for making steel. With the possible exception of some flotation processes in which quicklime is used as an aid to settling, and in the cyaniding of gold, practically all other metallurgical processes require limestone. In the basic Bessemer and basic open-hearth processes the lime in lump form is added to the charge. It serves two purposes: (1) It prevents excessive wearing of the linings and (2) combines with the phosphorus and is run off with the slag. About all that can be said relative to the requirements of lime for these purposes is that it should be low in silica and other impurities and of high calcium content, since the presence of magnesia affects adversely the fusibility of the slag and impurities necessitate a greater consumption of heat in the furnace.

Refractories.—If reference is made to the values given on page 77 it will be noted that appreciable quantities of lime are required in the manufacture of refractory lime (dead-burned dolomite). Inasmuch as the processes used in the United States vary greatly, and the details are more or less trade secrets, the type of lime most suitable in all cases can not be stated.

Table 7 indicates briefly the grade of lime desirable in a number of industries in which the individual annual consumption of this commodity is relatively small.

TABLE 7

Use	Desirable properties
Absorption of CO_2	Q, 90 per cent A. L.; H, 85 per cent A. L. Fineness; H, 97 per cent through No. 200 sieve.
Manufacture of carbide and cyanamide	Free of P and As; low in S; high Ca. SiO_2, Al_2O_3, etc., reduce thermal efficiency.
Manufacture of potash from minerals	High Ca.
Purification of coal gas	H, slaked with excess water.
Distillation of wood	High Ca, low in SiO_2 and impurities.
Manufacture of citric acid	High Ca, very pure and free from As, P, etc., and iron.
Organic syntheses	Pure, low in magnesia and insolubles.
Manufacture of soda-lime	High Ca, and certain physical properties if hydrate.
Varnish manufacture	High Ca, H, very fine and free from iron.
Cold-water paints	H, pure white, finely divided, low in iron.
Textiles	High Ca, low in iron.
Sewage treatment	High Ca.
Rubber manufacture	H, very fine.
Filler in paper, rubber, etc	Do.
As a lubricant	Pure and grit free.
Manufacture of chlorates	Pure (Mg lime may be better).
Manufacture of bleaching powder	High Ca, free from Fe, Mn, and Mg "fat." Certain physical properties.
Chlorine manufacture	High Ca, containing very little Mg.
Sodium bicarbonate by Solvay process	High "availability," low in Mg.
Manufacture of caustic soda	Q, high Ca, free of clay, fast slaking.

Abbreviations: Q=quicklime; H=Hydrated lime; A. L.=available lime.

VII. APPENDIX

1. INTRODUCTION

In 1909 and in 1925 tours of inspection of lime plants were made. The itinerary included 24 typical plants, in various parts of the United States, some of which were visited twice in instances where an innovation had been installed. The methods of operation of quarries or mines, kilns, and hydrate mills were studied in detail. The following part of this paper consists of descriptions of the plants visited in 1925.[1] Information, such as chemical analyses of the products, is also included in some instances.

The data have been arranged in the following order:

I. Name of company, location of plant, and transportation facilities.

II. Quarries or mines: (1) Geology of deposit—age, bedding, strike, and dip. (2) Stone—physical properties and chemical analyses. (3) Quarry or mine—location, size of opening, direction of extension, and drainage. (4) Operation—stripping, drilling, blasting, sledging, sorting, and transportation. (5) Refuse—equipment and capacity of crushing plants and uses of products.

III. Kilns: (1) Construction—casings, tops, linings, dimensions, coolers, and fire boxes. (2) Operation—kind of fuel and method of firing, kind of draft, time of charging and drawing, sticking or following process, temperature and analyses of waste gases, temperature of interior of kiln, temperature of lime as drawn, capacity of kiln, and fuel consumption.

IV. Lime—drawing, cooling, sorting, uses and analyses.

V. Hydrate mills—equipment, uses of product and analyses.

2. DESCRIPTION OF TYPICAL LIME MANUFACTURING PLANTS

(a) ROCKLAND & ROCKPORT LIME CO., ROCKLAND, ME.

The Rockland & Rockport Lime Co. has operations extending about 6 miles along the coast of Maine, from Thomaston to Camden. The various plants have transportation facilities on the Maine Central Railroad, but rely chiefly on their own barge system, consisting of steam tugs and barges, and complete equipment for docking and loading, including electric trains to take the lime from the kilns to the docks.

A complete description of the stone used may be found in the Rockland Folio (No. 158) Geological Atlas of the United States, United States Geological Survey, 1908. The main deposit extends in a general northeasterly direction from the St. George River at Thomaston to Chickawaukie Pond. There are several more

---

[1] In view of the many changes which have undoubtedly occurred in the equipment, etc., of the plants visited in 1909 and not in 1925 the descriptions of them have been omitted in this edition. Reference has been made to the equipment then employed, but, for a complete detailed account the reader is referred to the first edition. The plants fully described in the first edition are the following:

Farnam-Cheshire Lime Co., Farnams, Mass.
Connecticut Lime Co., Canaan, Conn.
New Jersey Lime Co., Hamburg, N. J.
Thomasville Lime & Stone Co., Thomasville, Pa.
American Lime & Stone Co., Bellefonte, Pa.
E. Dillon's Sons, Indian Rock, Va.
Woodville Lime Products Co., Woodville, Ohio.
Tennessee Marble Lime Co., Knoxville, Tenn.
Lagarde Lime & Stone Co., Lagarde, Ala.
Ash Grove Lime & Portland Cement Co., Ash Grove, Mo.
Glencoe Lime & Cement Co., Glencoe, Mo.
Marblehead Lime Co., Marblehead, Ill.
Sheboygan Lime Works, Sheboygan, Wis.
Union Lime Co., High Cliff, Wis.
Manistique Lime Co., Manistique, Mich.

or less parallel outlying exposures on either side of the main deposit. The bedding is generally rather thin and irregular, with prominent jointing planes. The beds dip very steeply, 75 to 80°.

The deposit consists chiefly of three kinds of stone, which are known locally as "soft rock," "hard rock," and "Rockport rock." The soft rock is dark gray and coarsely crystalline. This is the best grade of high calcium stone, but some of it is so soft as to cause difficulty by falling to pieces in the kiln. The hard rock is denser and of a dark-blue color. It contains somewhat more impurities and magnesia than the soft rock. The Rockport rock is a coarsely crystalline dark-gray dolomite. Its name is derived from the fact that it is quarried near Rockport. A large part of all the grades of stone carries visible amounts of iron pyrites and sometimes the quantity of this impurity is so high that the rock can not be used to make lime. The following analyses were made by the United States Geological Survey in 1909:

	Soft rock	Rockport rock
	Per cent	*Per cent*
Silica (SiO_2)	1.29	2.41
Iron (Fe_2O_3)	.35	.40
Alumina (Al_2O_3)	.15	.22
Calcium carbonate ($CaCO_3$)	95.91	85.18
Magnesium carbonate ($MgCO_3$)	2.27	11.72
Total	99.97	99.93

The main quarry examined, known as the Nellie Ulmer and located a short distance west of Rockland, is shown in Figures 18 and 19.

Since the beds of rock are almost vertical it follows that, in order to work one bed only, the opening must extend either along the strike or down into the ground along the dip. Unfortunately, the amount of available stone along the strike is limited. To the south of the present opening the quality of stone in the same bed deteriorates; to the north the bed is covered by a lake. A bed of soft rock is being followed straight down, and smaller quantities of hard rock are taken from the beds on either side of it. The quarry as shown measures about 1,000 feet along the strike, 125 feet wide at the top, 40 feet wide at the bottom, and 350 feet deep. The bottom of the quarry is below drainage level, necessitating pumping. It occasionally becomes necessary to widen the opening at the top in order to prevent the sides from becoming so nearly vertical as to be dangerous. This entails stripping, but the amount is relatively negligible.

Holes are drilled in the stone by means of steam drills and the material is blasted out with dynamite and sledged to the size required. The stone is then sorted. The soft rock and hard rock are both used, but are burned in separate kilns. The spawls, and any stone which contains too much pyrites, are discarded. The stone is loaded by hand on wooden skips, which are hoisted by derricks and dumped into 2-cubic-yards-capacity cars of the Lime Rock Railroad Co. The cars are then taken by a steam locomotive to the plant where they are drawn up a trestle and dumped into the stock pile.

The spawls and quarry refuse are used locally to some extent for ballast and road "metal," and small quantities have been shipped for furnace flux. A crushing plant located at the quarry is operated only occasionally.

The company owns approximately 80 kilns, but only those located at Rockland, numbering about 36, were inspected in 1925. The most modern of these are 6 modified Mount kilns and 7 ordinary shaft type kilns.

The modified Mount kilns are about 80 feet high from the drawing floor to the top, which is 55 feet above the gas ports; and are 9 feet internal diameter at

Fig. 18.—*Quarry of the Rockland-Rockport Lime Co., Rockland, Me.*

Fig. 19.—*Quarry of the Rockland & Rockport Lime Co., Rockland, Me.*

the top and elliptically shaped (5 by 6 feet in the hot zone). Firing is by producer gas from two Morgan producers equipped with automatic regulators for maintaining a uniform gas pressure. The gas from both producers is led into one feed pipe which discharges through two eyes on the 6-foot side of each kiln. The air for the combustion of the gas is admitted on the same level as the gas. The waste gases are drawn off 25 feet below the top of the kiln, inasmuch as the portion of the kiln above this point acts as storage for cold stone. The rock from the stock pile is drawn through gates into skips on a moving skip hoist and so elevated to the top of the kilns. The kilns are drawn 10 times a day and produce about 25 tons of lime each per 24 hours with a fuel ratio of 1 : 3.5. The burned lime drops from the kilns to a drag conveyor which delivers it to the packing house.

The seven ordinary shaft type kilns are known as the Gregory battery, and consists of vertical steel cylinders, lined with fire brick. The tops are left open. The brick lining is capped with two courses of granite, which offers a better resistance to the abrasion of the stone. The inside dimensions of these kilns are: 9 feet square at the top and drawn into a rectangle 7½ by 5 feet at the fire boxes; total height, 44 feet; height from bottom of cooler to grate level, 13 feet. The coolers are also lined with fire brick and are provided with shears through which the lime is drawn. Each kiln has two fire boxes, 42 inches wide, by 6 feet long, by 2½ feet high to the crown of the arch. The grate area is only 4½ feet long, the rest of the fire box being taken up by a dead plate in front and the bridge wall in back. A pillar 14 inches square supports the arch at the inner end of the fire box, where it enters the kiln.

The fuel used in all of the shaft kilns and in the gas producers is West Virginia slack. In the operation of the ordinary type shaft kilns at this plant a thick bed is maintained and is replenished whenever the fireman thinks it necessary. A very small amount of steam is blown into the ash pit. This is not enough to create any appreciable forced draft, but serves primarily to keep the grate bars free from clinkers. The air used for combustion is taken in over the fire, the door of the fire box being generally left open for this purpose. The kilns are filled up with stone twice a day, and the lime is drawn out every three hours. For about half an hour before drawing the fire is permitted to die down, which chills the kiln and causes the lime to stick to the sides until it is knocked down by bars inserted through the fire boxes. The fires are cleaned after each draw. The temperature of the stack gases averaged about 200° C. and the temperature of the interior of the kiln, measured through the fire box, about 1,350° C. The figures furnished by the company indicate that these kilns have a capacity of about 13 tons of lime per kiln day, with a fuel ratio of about 3.5 pounds of lime per pound of coal. This latter does not include the heat used in generating the steam blown into the ash pits. The lime is drawn into iron buggies, after which it is dumped on the floor to cool. When cold it is sorted, the fine stuff being sent to the hydrate mill and the lump to one of four steel bins.

En route to the packing house the lime from the modified Mount kilns is sorted. The lumps from this source are barreled and are sold for chemical purposes. The fine material goes to the hydrate mill.

The hydrate mill consists of two Kritzer hydrators. One is used in the manufacture of mason's and chemical hydrate and the other in the manufacture of agricultural hydrate. The lime which is used in the manufacture of mason's and chemical hydrate is put through a roll crusher, a Sturtevant hammer mill, and is screened through a 50-mesh screen before being hydrated. The lime used in the manufacture of agricultural hydrate goes through an Emery roll crusher and a 30-mesh screen before hydration. After hydration the chemical and mason's hydrates are put through one of two Raymond impact mills. The rejects are discarded. These classes of hydrates then go to bins from which the hydrates are drawn through Urshel-Bates packers.

The hydrate has been analyzed, with the following results:

	Soft rock (analysis furnished by company; authority not stated)	Best grade (analyzed by Bureau of Standards)
	Per cent	*Per cent*
Silica (SiO_2)	1.08	0.42
Iron (Fe_2O_3) and alumina (Al_2O_3)	.89	.21
Lime (CaO)	73.02	72.25
Magnesia (MgO)	.61	1.47
Water, (H_2O)	24.40	24.98
Carbon dioxide (CO_2)	----------	.57
Total	100.00	100.23

At the Rockland operation about 1,000 tons of rock are quarried per day. All but a very small quantity of this is burned. The major portion of the finished products is shipped to New York and Boston in barges owned and operated by the company.

(b) CHARLES WARNER CO., CEDAR HOLLOW, PA.

The Cedar Hollow plant of the Charles Warner Co. is located in Chester County Pa., about 2 miles from Cedar Hollow, which is on the Philadelphia & Reading Railway and one-half mile from Devault, which is on the Pennsylvania Railroad. Shipping facilities over both roads are provided by private sidings running to the plant.

A deposit of Shenandoah limestone forms the main body of a chain of hills which run in a general northeasterly direction. The stone strikes about south 75° west and dips at about 60° toward the southeast. The beds of stone are not distinct, and the deposit is cut by frequent and prominent jointing planes.

The stone is a fine-grained dolomite which varies in color from blue to yellow. It also varies somewhat in composition as is shown by the following analyses of the United States Geological Survey, made in 1909:

	East end southern quarry	West end southern quarry	North quarry	Whiteland quarry
	Per cent	*Per cent*	*Per cent*	*Per cent*
Silica (SiO_2)	0.81	0.91	2.27	0.94
Alumina (Al_2O_3)	.56	.09	.51	.15
Iron (Fe_2O_3)	.47	.30	.40	.45
Calcium carbonate ($CaCO_3$)	54.68	63.02	53.16	54.09
Magnesium carbonate ($MgCO_3$)	43.66	35.78	43.89	44.58
Total	100.18	100.10	100.23	100.21

The plant is situated between two hills, both of which are formed by this limestone. Two quarries have been opened by cutting into these hills, the quarry floor having been maintained at first on a level with the ground at the plant. However, this procedure did not prove economical beyond a certain point and now a face of about 50 feet comprising two 25-foot benches, both of which are below the level of the plant, is worked. In the southern quarry the working face is about 700 feet long and the working face of the northern quarry is about 300 feet long. A third quarry is located at Whiteland, about a mile away and along the strike of the stone; it is more or less circular in shape, about 400 feet in diameter by 50 feet deep.

Fig. 20.—*Plant and docks of the Rockland & Rockport Lime Co., Rockland, Me.*

The stripping averages about 6 feet of red clay, but pockets are occasionally found in which it is much deeper than this. Whenever possible it is removed by means of a steam shovel and hauled away in cars. Holes are drilled horizontally in the stone by means of compressed air. These are sprung with black powder, and the final blast is made with dynamite. After being sledged the stone is sorted. Each bed, as it is opened, is analyzed and the analysis determines whether it can be used in the manufacture of lime. A sample such as that from the north quarry given in the table above would be rejected. The good stone is loaded by hand into cars, which are hauled by horse to the foot of a tramway, and taken by cable out of the quarry where gas locomotives transport the cars and rock to the kilns.

In a similar manner the rejected stone is taken to a crushing plant. This is equipped with one 4 by 5 foot Traylor jaw crusher, a dryer, a grizzly, a small recrushing plant and Fuller-Lehigh mills. The capacity is about 600 tons per day, and comprised material of five sizes. It is used chiefly for road metal, ballast, concrete, fertilizer, and asphalt filler.

This company operates, at this location, 16 shaft kilns, including 1 recently installed Mount kiln and 1 rotary kiln. A battery of 7 of the more modern shaft kilns, the Mount kiln, and the rotary kiln were examined. The 7-kiln battery referred to was erected in 1921. The outside shell dimensions of each of these kllns are—diameter, 12 feet 9 inches; height, 31 feet. The shell is of steel plate. The kilns are lined with an outer layer of common brick with two inner layers of refractory brick. A 2-inch thickness of diatomaceous-earth insulating material between the shell and the common brick surrounds the furnace proper and extends for a distance of 8 feet up the kiln. The top 15 feet of the kilns is used for storage, and each kiln has a capacity for preheating 40 tons, which is sufficient to carry over from Saturday to Monday. The internal cross sections of the kilns vary. At the furnaces they may be 7 feet by 6 feet, 7 feet by 6 feet 6 inches, or 7 feet by 5 feet 9 inches. Each kiln is provided with two furnaces located opposite each other and 37 inches deep by 42 inches wide. From the kilns the lime passes through short coolers to one of two portable conveyors which empty into cars running on 24-inch gauge tracks. The cars are used to transport the lime to an elevator which hoists it to bins.

The Eldred process of combustion is used on all of the kilns and the fuel is Fairmont, W. Va., coal. One kiln is fired by gas from a Morgan producer. An interesting feature is that one fan takes the gas from all of the kilns and delivers it to all of them. Means are provided to regulate the amount of this gas and of the air supplied to each kiln. The sticking process is used in operating the kilns; that is, the lime is caused to stick to the sides of the kiln until it is knocked down with bars. A thin fire is generally carried in the grates and is replenished about every five minutes. The stone is charged at no stipulated intervals, but whenever it comes from the quarry. The lime is drawn out every four or six hours. The fuel ratio (pounds of lime per pound of coal) averages about 4.5 exclusive of the power used to create the draft.

Each kiln has its own cooling floor immediately under it, so the lime is merely drawn to this and allowed to further cool. When cold it is shoveled to a belt conveyor, which runs the entire length of the plant in front of each kiln. This conveyor takes the lime to a revolving wheel provided with slats which act as a coarse screen. The lump lime passes over the wheel, goes up another conveyor, and down a chute into the car. The core is sorted as it comes down the chute and is thrown away. The fine stuff which falls through the wheel passes through a crusher and then goes to the fine-lime bin.

The rotary kiln is 150 feet long by 8 feet in diameter, and is fired by gas from a Morgan producer. Three-quarter inch stone from the crushing plant is fed into the kiln. The lime from the rotary is reduced in hammer mills and then deposited in the ground-lime bin. Material from the bin containing fine lime from the shaft kilns is also put through hammer mills and finally deposited in the ground-lime bin.

The ground-lime bin product is put through a tube mill for further reduction before going to the pulverized-lime bin, from which it is fed to a Clyde hydrator. After passing through the hydrator the lime is carried by means of a drag conveyor to an elevator which, in turn, deposits the lime into a storage bin, where it is allowed to remain sufficiently long to insure complete hydration. From the bin the lime is passed through either a Raymond impact mill or a tube mill, depending upon the product being made. If the former is employed the tailings are discarded. The finished products are sacked by means of automatic baggers.

(c) PALMER LIME & CEMENT CO., YORK, PA.[2]

The plant of the Palmer Lime & Cement Co. is located about 2½ miles west of York, in York County, Pa., on the Pennsylvania Railroad. The limestone here forms the bedrock of a rolling country. The slight elevations are caused partially by the gradual folding of the stone and partially by an increase of thickness of the overlying impure limestone and shale. Where the deposit has been opened, the stone is found in thick well-defined beds, which strike north 65° west and dip 55° toward the southwest. The beds are broken by prominent jointing planes, and lodes of a different kind of limestone have been found in the deposit.

The main beds are either white or blue in color. The blue stone is very hard and dense and is microcrystalline; the white stone is somewhat coarser and softer. The stone found in the lodes appears to consist of nodules of the white variety embedded in a matrix of the blue, but is harder than either. Owing to this peculiar appearance it is locally designated "calico stone." The following analyses show the compositions of the various kinds of stone:

	White		Blue		Calico	
	E. R. Squibb & Son, 1908	United States Geological Survey, 1909	E. R. Squibb & Son, 1908	United States Geological Survey, 1909	United States Geological Survey, 1909	Bureau of Standards, 1911
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Silica (SiO_2)	0.30	0.53	0.20	0.14	0.27	0.25
Alumina (Al_2O_3) Iron (Fe_2O_3)	.38	.04	.19	.02	.07	.03
Calcium carbonate ($CaCO_3$)	98.21	99.21	[1] 100.21	98.73	86.43	81.73
Magnesium carbonate ($MgCO_3$)	2.12	.74	.32	1.01	12.98	18.50
Total	101.01	100.57	100.92	100.00	100.05	100.78

[1] This figure was given as 56.12 per cent calcium oxide and has been calculated.

The deposit has been opened by sinking a circular pit in the ground and gradually enlarging both the diameter and the depth. In 1912 the quarry was about 330 feet north and south, by 550 feet east and west, by 20 feet deep. In 1925 all of the dimensions had increased considerably; the depth was 50 feet. The floor of the quarry is below water level and is drained to a sump hole, from which the water is removed by means of a pump.

The clay or shale overburden varies from 3 to 6 feet in thickness, and is removed either by hand or a steam shovel. The stone is then drilled by means of a churn drill, for the large shots, or compressed air for the smaller shots. Forty per

---

[2] This plant is now owned and operated by the Universal Gypsum & Lime Co., Chicago, Ill.

cent dynamite is used in either case. After having been blasted down the stone is sledged and sorted. The impure cap rock and the spawls are rejected, and the calico stone is separated from the blue and white varieties because it retains the same mottled appearance after burning and is unsalable as lump lime. It must, therefore, be burned in separate kilns. The good stone is loaded by hand into 2-cubic yard V-shaped cars, which are drawn by mules to the foot of an incline. A cable hauls the loaded cars up this to either the tops of the kilns or to the crushing plant. About 200 tons of rock per day go to the crusher and 400 tons to the kilns.

The crushing plant consists of a Farrell jaw crusher and a rotary screen. It is used for crushing the cap rock and spawls to ballast or road metal. In connection with it there is also a Williams hammer mill, a Universal mill, Raymond roller mills, and a 56 by 6 foot coal-fired Ruggles-Coles dryer used in producing first-quality limestone for chemical purposes. Two Bates four-spout automatic baggers are used in this connection.

There are 12 kilns at this plant; 10 are in one battery and are alike, while 2 are much larger and employ the Schmatolla system.

Each kiln of the battery of 10 consists of a steel shell lined with fire brick, backed by paving brick, and closed at the top by steel plates. These plates are provided with pipes, through which the waste gases are removed, and with doors for charging the stone; the latter are sealed after the kiln has been filled. The linings are of two grades of fire brick—a highly refractory variety in the burning zone and a "harder" type at the top. The inside shape is circular and 6½ feet in diameter. The walls are straight and extend 35 feet above the grates and 9 feet below. The coolers are also lined with brick and are provided with shears through which the lime is drawn. Each kiln has two fire boxes, one on each side. These are 4 feet wide by 7 feet deep by 28 inches high. The fuel used is Pennsylvania gas coal, and the draft is created according to the Eldred process, using two fans. The kilns are filled with stone once a day and the lime is drawn out every four hours. As the lime is removed the stone is permitted to follow it down by gravity. The fuel beds are kept thin and are replenished about every 20 minutes. The coking process of firing is used; that is, the coal is put on the dead plate in front of the grates and is gradually pushed back into the fire box as fresh charges are added. The fires are cleaned twice a day, the clinkers being removed from one side at a time, so that the kiln is never permitted to cool down appreciably. The average temperature of the waste gases is about 55° C. and the temperature of the interior of the kilns about 1,250° C.; the lime is red to white hot when drawn. An average of the gas analyses made is: Carbon dioxide, 18.1 per cent; oxygen, 9.2 per cent; carbon monoxide, 0 per cent. From data obtained by this bureau in 1911 these kilns have a daily average capacity of 10.6 tons of lime, with a fuel ratio of 3.78 pounds of lime per pound of coal. The coal equivalent of the power used to create the draft is included in calculating this fuel ratio.

The two large kilns employing the Schmatolla system are 25 feet in external diameter and are 90 feet from top to drawing floor. The tops are flat and covered by steel plates which contain two doors for the admission of stone. The inside shape is circular, 19 feet in diameter, and lined in a manner similar to the smaller kilns. The cooling zone of these kilns is divided into two sections, and each section is provided with two ports for drawing the lime directly into 1-ton cars. Twelve gas inlets, located 20 feet above the drawing floor, are contained in each of the kilns. One automatic Chapman and two hand-fired producers, all three connected to the gas mains, supply the fuel. Pennsylvania gas coal is used in the producers. The kilns are drawn every four hours.

The lime from the small kilns is drawn on to a drag conveyor which discharges into 2-ton electric cars. That from the large kilns is discharged directly into 1-ton electric cars. The lime from all the kilns is transported to a bucket elevator which discharges it over a screen with 1-inch openings. The material passing the screen is conveyed by screw to a Williams mill, the coarse stuff being carried to a cooling bin by means of a drag conveyor. From the cooling bin the quicklime is transported up an incline by a drag conveyor, where it is hand picked en route and delivered to a one-half inch shaker screen. The material retained in the screen either goes to cars for bulk shipments or is barreled. The fines from the screen are carried by a belt conveyor to a storage bin after first passing through a Williams hammer mill to reduce any lumps.

From the storage bin the material is delivered to the hydrators by means of a bucket elevator. The hydrating equipment consists of one Schaffer and one Kritzer hydrator. The Schaffer is customarily used and the Kritzer occasionally. The former has a capacity of 16 tons of hydrate per hour. From the hydrator the product passes through one of two Raymond impact mills before reaching storage bins. The storage bins are two in number and each is equipped with a Bates four-spout automatic bagger. The composition of the hydrate is shown by the following analyses:

	E. R. Squibb & Sons, 1908		Bureau of Standards, 1911
	Made from first quality lime	Made from second quality lime	
	Per cent	*Per cent*	*Per cent*
Silica (SiO_2)	0.30	Trace.	0.95
Iron (Fe_2O_3)	Trace.	Trace.	.51
Alumina (Al_2O_3)	Trace.	Trace.	.50
Lime (CaO)	75.44	75.20	71.66
Magnesia (MgO)	Trace.	Trace.	.36
Water (H_2O)	24.15	24.55	23.81
Carbon dioxide (CO_2)	----------	----------	1.80
Total	99.89	99.75	99.59

The power for the operation of the plant is obtained from the York city lines. There is operated in conjunction with the lime plant a plant for the manufacture of precipitated chalk having an output of fifty 175-pound barrels daily.

(d) RIVERTON LIME CO., RIVERTON, VA.

The plant of the Riverton Lime Co. is about one-half mile from Riverton, Warren County, Va. Riverton is the junction point of the Southern and Norfolk & Western Railroads, but the plant is located on the main line of the latter. The topography of this locality is shown by the topographical map of the Luray quadrangle, published by the United States Geological Survey in 1905.

The deposit of Shenandoah limestone of Cambro-Ordovician age has been folded into an anticlinal formation, which strikes about north 25° east. The beds are massive, and their dip varies from vertical to 60° toward the southeast. Bedding and jointing planes are prominent, and numerous large pockets between the beds have been filled with gravel and other foreign material.

The stone is dark gray or blue, fine grained, and very dense and hard. One bed, 30 feet thick, contains pure high calcium stone; two others with a thickness of 58 feet contain considerable amounts of magnesia, and the stone from them is burned in separate kilns. The stone from the other beds is too impure to use in the manufacture of lime, but it is crushed and sold for road metal or ballast.

The stone from the different beds can be readily distinguished by its appearance. The following analyses show its composition:

	Magnesian, United States Geological Survey, 1909	High calcium	
		United States Geological Survey, 1909	Bureau of Standards, 1911
	Per cent	*Per cent*	*Per cent*
Silica (SiO_2)	0.87	0.44	0.32
Iron (Fe_2O_3)	.08	.15	.12
Alumina (Al_2O_3)	.48	.04	.23
Calcium carbonate ($CaCO_3$)	90.97	98.02	98.20
Magnesium carbonate ($MgCO_3$)	6.83	.64	1.37
Total	99.23	99.29	100.24

At a point near the kilns the stone was found to outcrop on the side of a hill. Starting here, an opening was cut for a considerable distance into the hill along the strike of the stone. However, recent operations have been moved from this location to about 1,000 feet away from the kilns and across the Shenandoah River, where more extensive deposits of excellent stone were found which could be worked to greater advantage.

The stripping, which occurs in pockets often of considerable depth, is removed by hand. The rock usually is drilled by compressed air, although occasionally a well digger is resorted to; and is blasted with 35 per cent dynamite. After sledging it is loaded by a steam shovel into cars of 3-tons capacity. The loaded cars are attached to a cable and drawn across the river over a trestle to the crushing plant. Upon reaching the crushing plant the cars are discharged into a large jaw crusher, which, in turn, discharges into a rotary screen; the screen separates the rock of 7 inches and over from that of less dimensions. The material of 7 inches and over goes to a bin, to cars, or (by means of a belt conveyor) up an incline under which is located a storage pile for rock for the kilns. The fine stuff goes to bins and is disposed of as ballast or road metal.

There are eight kilns. Five are direct-fired and three gas-fired by one large gas producer designed by Mr. Carson, the president of the company. Each kiln is incased in stone at the burning zone and steel above the burning zone and is lined with fire brick. The tops of all of the kilns are closed by flat plates, but those of the direct-fired kilns carry mains leading to a stack for induced draft on top of the adjacent hill. On the other hand, the gas-fired kilns are controlled by dampers located in short stacks surmounting the kilns. The linings of all of the kilns are circular at the top and, in the direct-fired kilns, are drawn in to ellipses 7½ by 5½ feet at the burning zone. The gas-fired kilns are slightly larger in cross section. All are 35 feet high above the grates. The coolers are lined, but are provided with flues in the lining through which the air for combustion is taken. The kilns are provided with shears for drawing the lime. The direct-fired kilns have two fire boxes each, one on each side. In these kilns the grates are 42 inches wide by 55 inches deep and have a bridge wall 26 inches wide at the back. This supports a pillar 26 by 13 inches.

West Virginia gas coal is used in the grates and in the gas producer. The forced draft for the direct-fired kilns is created by steam jets opening into the ash pits. The fires are kept thin and well coked and are replenished regularly every 20 minutes.

Stone is charged into the kilns whenever it comes from the quarry. The lime is drawn every six hours. The fire is permitted to burn out just before the draw, so that the kiln is chilled somewhat, and the lime is caused to stick to the sides of the kiln until it is knocked down with bars.

The stack gases show an average temperature of about 200° C. and analyze 15.5 per cent carbon dioxide, 7.1 per cent oxygen, and 0.4 per cent carbon monoxide. The temperature of the interior of the kiln is about 1,300° C., and the lime is drawn red to white hot. Measurements made upon the direct-fired kilns by this bureau in 1911 indicate a capacity of 12.6 tons of lime per kiln per day with a fuel ratio of 4.29 pounds of lime per pound of coal. This latter figure includes the heat used to generate the steam under the ash pits.

The lime is drawn on to a drag conveyor, which discharges into a bucket elevator which in turn discharges by gravity down a chute on to another drag conveyor. This latter conveyor delivers to a roller mill. There are two conveyor systems as described, one taking care of the lime from the five direct-fired kilns and the other handling the lime from the three gas-fired kilns. The lime is sorted on the second drag conveyor and the chute.

After going through the roller mill the lime either passes through a hammer mill, after which it is picked up by an air current and carried across the railroad tracks to the hydrate mill, or the roll and hammer mill treatment may be omitted and the lump lime passed over a grid to eliminate the fines. The coarse material is bagged as "pebble lime" or barreled as lump lime. The fine stuff through the grid goes to the hydrate mill.

The composition of the lime burned from the magnesian stone, as found by the United States Geological Survey in 1909, is shown by the following analysis:

	Per cent
Silica (SiO_2)	1. 22
Iron (Fe_2O_3)	. 31
Alumina (Al_2O_3)	. 25
Lime (CaO)	87. 04
Magnesia (MgO)	10. 63
Carbon dioxide and water (CO_2 and H_2O)	. 36
Total	99. 81

On reaching the hydrate mill the air conveyor discharges the ground lime into a 20 by 5 foot wind-swept tube mill where it is further reduced before deposition in a storage bin located above the hydrator, which is fed by gravity.

The hydration of the lime is accomplished by the Carson system with a capacity of about 85 tons of finished product per day. The storage bin which receives the partially hydrated material, and which is an integral part of the hydration process, discharges into a Fuller-Lehigh mill after which the hydrate goes to the packers. There are 7 hand packers, 6 for taking care of the usual sized bags and 1 for bagging small sacks of garden lime. This plant is equipped throughout with a most complete dust removal system which has improved greatly the working conditions, especially on the drawing floor and in the hydrate packing house.

(e) OHIO HYDRATE & SUPPLY CO., WOODVILLE, OHIO

The plant of the Ohio Hydrate & Supply Co. is located in the town of Woodville, Sandusky County, Ohio, on the Pennsylvania Railroad. The topography of this district is shown by the topographical map of Elmore quadrangle, published by the United States Geological Survey in 1903. The deposit consists of thick horizontal beds, which lie close to the surface of a level country. The bedding is even and regular with few joints or seams. The upper beds show the effect of weathering, being very soft and porous, and containing numerous small pockets filled with calcite crystals.

The stone is a soft, oölitic, fossiliferous dolomite. It is normally yellow in color, but weathers to gray or blue. Its composition as determined by the United States Geological Survey in 1909 is:

	Per cent
Silica (SiO_2)	0. 34
Iron (Fe_2O_3)	. 15
Alumina (Al_2O_3)	. 02
Calcium carbonate ($CaCO_3$)	56. 79
Magnesium carbonate ($MgCO_3$)	42. 92
Total	100. 22

The quarry is located adjacent to the mill, and has been worked into the shape of a circular pit covering an area of about 5 acres. The average depth is about 50 feet. Very little stripping is necessary but when it is removed hand methods are employed. A well digger is used to drill the holes for bringing down the large masses of stone and 40 per cent dynamite is used as the explosive. "Pop shooting" is resorted to for breaking up the large pieces, drilling being done by air drills.

The "one-man stone" is loaded by hand into 2-cubic-yard-capacity, 36-inch-gauge side-dump cars, which are conveyed to the lower end of a skip by a gasoline locomotive. The loaded cars are taken up the skip by means of a cable. The rock may be delivered into a storage bin or it may go directly to the kilns.

In 1925 this plant had in operation 24 hand-fired modified Arnold and Weigel kilns. The kilns were 52 feet from drawing floor to top, with an elliptical cross section, at the burning zone, 7 by 4 feet. Each kiln was equipped with two firing doors, one on each side. They were drawn every 4 hours and made an average of 15 tons of lime per day of 24 hours. The company chemist reported a fuel ratio of 3¾ pounds of lime per pound of coal. Steam is introduced under the grates to produce a forced draft. To provide steam for the grates and for operating the pump supplying the water to the hydrator, two 150-horsepower and one 125-horsepower Adam J. Luse boilers are used. Two air compressors for the drills are driven by electric motors drawing current from the city lines.

The quicklime is drawn through shears into 2-cubic-yard-capacity cars, which are carried to scales where the lime is weighed and taken up an incline by a gasoline locomotive. On arriving at the top of the incline the cars are discharged into a bin of 500 tons capacity. The quicklime is drawn out of the bin through an opening onto a drag conveyor, which discharges into a Williams hammer mill. En route the lime is sorted by hand, the core and overburned material being discarded. From the Williams mill the lime may be transported to the crushing plant, where it is further reduced by another hammer mill and is sized by being passed through a Rotex screen or, as is the case with the majority of the product, it may go to the hydrators. These are two in number and are the standard Schaffer design. Depending on the class product desired, the lime after being hydrated passes through either a Raymond heater, a Raymond roller mill, or a Bonnet mill. The Bonnet mill equipment consists of one large size mill and two of smaller size. From the mills the finished product is bagged by Bates automatic bagging machines, of which there are four of the four-spout type. The capacity of this mill is 35 tons of hydrated lime per hour.

(f) THE KELLEY ISLAND LIME & TRANSPORT CO., MARBLEHEAD, OHIO

One of the several plants of the Kelley Island Lime & Transport Co. is located at Marblehead, Ottawa County, Ohio, on the Lakeside & Marblehead Railroad, which is a short line connecting with the New York Central. The latter is about 1 mile distant from the shipping room of the plant.

The topography of this district is shown by the topographical map of Kelleys Island quadrangle, published by the United States Geological Survey in 1916.

The deposit of stone worked is of the Columbus formation, which dips slightly to the south and east. While this formation is probably 40 feet or more in thickness at the Marblehead quarry, it merges on the surface into a hard "cap rock" of variable silica content and the lower strata include the Helderburg formation. Consequently, it has been found desirable to work only a 20-foot face. The stone is massive, crystalline, and of light color. It is stratified into ledges of 1 to 3 inches in thickness, which eliminates any further reduction in size after it is brought down. There is very little stripping, but what is necessary is removed by plowing, followed by a steam shovel.

The following analyses from Orton and Peppel[3] give a very good idea of the composition of the stone from the various ledges:

Description of the sample	"Cap rock"	"Bottom rock"	2 feet 6 inches below "bottom rock"	1-foot stratum below preceding sample
Silica (SiO_2)	1.50	1.63	5.64	42.02
Alumina (Al_2O_3)	.22	.90	.56	.70
Oron oxide (Fe_2O_3)			Trace.	Trace.
Calcium carbonate ($CaCO_3$)	84.51	69.61	58.30	36.10
Magnesium carbonate ($MgCO_3$)	13.31	27.42	36.35	21.58
Total	99.54	99.57	100.85	100.40

After the overburden has been removed the stone is drilled by steam drills and blasted with 40 per cent dynamite. The "shot rock" is loaded into side-dump cars of 10 cubic yards capacity by a steam shovel and trains of the loaded cars are transported by locomotive to the lime plants or crushing plants.

At this location there are two separately operated lime plants and two separately operated crushing plants. These are all located on the floor of the quarry the extent of which exceeds 500 acres.

Crushing plant.—The stone is discharged from the cars into one of two No. 24 Allis-Chalmers gyratory crushers. It is here reduced to 10 inches or less. These crushers discharge into 60-inch bucket elevators which carry the rock to the top of the plant and empty it into one of two squirrel-cage screens 24 feet long by 5 feet in diameter. The material over 4 inches in diameter is either crushed in one of two No. 8 Allis-Chalmers gyratory crushers and returned to the screens, or it is sent to the lime kilns. The material 2 inches in diameter or less is further screened in one of two squirrel-cage screens, which are 48 inches long by 20 inches in diameter. Further, the stone seven-eighths inch in diameter or less is screened on four double-deck shaker screens. These screens are one-half inch and three-eighths inch, 5 feet by 10 feet. The material passing the three-eighths inch screen is carried by a belt conveyor and discharged into a 20-foot by 4-foot rotary screen for final grading. Each of the different sizes goes into a separate bin, from which it may be drawn directly into cars on the tracks alongside of the plant.

The capacity of this plant is 10,000 tons per day. Thirteen hundred horsepower required for its operation is obtained from the power company's lines. The plant is operated on the unit drive system.

Drier plant.—The raw material for this plant is three-eighths inch or less and is delivered in cars from the crushing plant. The cars discharge into a bucket

---

[3] The Limestone Resources and the Lime Industry in Ohio. Bulletin 4, geological survey of Ohio, 1906.

elevator which, in turn, delivers the stone to one of two coal-fired rotary driers, one 7 feet in diameter by 56 feet long, equipped with Jones stokers, and the other, 8 feet in diameter by 24 feet long, equipped with a Cummins stoker. The product discharged from the longer drier is fed through one of two Kent mills, while the material from the shorter drier goes through a Bonnet mill with a 45-mesh screen. The products of the Kent and Bonnet mills are stored in seven bins having a total capacity of 8,000 tons. The bagging equipment consists of one 2-spout Bates automatic bagger and two 4-spout baggers of like make. This finely ground limestone is sold primarily as asphalt filler and as agricultural limestone.

Lakeside lime plant.—The stone burned at this plant is the oversize from the crushing plant. It is brought from the crushing plant and up an incline to the top of the kilns by locomotive.

The kilns are 10 in number with steel shells and lined with fire brick. The cross section of the burning zone is elliptical, 4 feet 8 inches by 5 feet 6 inches, with no increase or decrease in either dimension from the bottom of the preheating zone to the top of the cooler. They are 20 feet in height from the firing floor to the top. The tops are open. Each kiln has two fire boxes, one on each side, which are fired by hand. Steam at 25 $lbs./in.^2$ is released under the grates for forced draft and the kilns are drawn every four hours through shears. About 7 tons of quicklime is burned per day per kiln.

The lime is drawn into buggies, which are dumped onto the floor where the lime is sorted. It is then loaded into cars for bulk shipment, dumped into or carried by a pan conveyor to a Sturtevant No. 3 gyratory crusher, which reduces the quicklime to one-fourth inch or less for hydration. After crushing the lime is elevated to a bin which feeds directly to the hydrators. The hydrating equipment consists of two Clyde hydrators with a daily output of 35 tons. The product of the hydrators is elevated and conveyed to one of thirty-two 20-ton capacity bins. A drag conveyor carries the lime from the bins and discharges it into a Lehigh mill, after which it goes to bins above the bagging machine. The packing is done by one 4-spout Bates automatic bagger.

The power for this plant is obtained from two Erie City boilers, which supply steam to the kilns and run a 125-horsepower Corliss engine which operates the hydrate plant.

Marblehead lime plant.—Rock from the crushing plant, of the same size as that furnished the Lakeside plant, is burned also at this plant. However, five of the kilns are employed to burn high calcium rock from Calcite, Mich., and some "cap rock" is also burned in separate kilns. Locomotives transport the cars loaded with rock to the top of the kilns.

Fifteen kilns arranged in three batteries of five kilns each, all except two of which are of the same size and operated in the same manner as at the Lakeside plant, constitute the kiln equipment. The two kilns which are different are of approximately the same size but are Arnold and Weigel standard type. The burned lime is drawn from all the kilns every four hours and the output of each is 15 tons per day.

After being drawn into buggies the lime is spread on the floor and sorted, and is then put through a No. 2 Pennsylvania hammer mill and elevated to the hydrator. In this plant the Carson system of hydration is employed. The lime from the hammer mill is put through a pug mill and then goes to a bin to allow the hydration to proceed to completion. The product is drawn from the bin and passed through a roller mill, after which it is ready for bagging. This is done by Bates automatic packers.

The composition of the quicklime and hydrated lime from the two plants is shown by the following analyses made at the Bureau of Standards:

	Quicklime Lakeside plant	Hydrated lime, Lakeside plant	Quicklime, Marblehead plant, Mich., stone
	Per cent	*Per cent*	*Per cent*
Silica (SiO_2)	2.39	1.51	0.22
Iron (Fe_2O_3)	.16	.25	.29
Alumina (Al_2O_3)	.40	.50	.44
Lime (CaO)	81.25	63.48	98.24
Magnesia (MgO)	15.00	10.37	.46
Water (H_2O)		18.96	
Carbon dioxide (CO_2)	.32	5.00	.32
Total	99.52	100.07	99.97

(g) LOUISVILLE CEMENT CO., MILLTOWN, IND.

The lime plant of the Louisville Cement Co. is located at Milltown, Crawford Co., Ind., on the Southern Railroad.

The deposit of rock, which lies adjacent to the plant, is composed of high calcium, coarsely crystalline stone and is of dense structure, varying from light gray to white in color. The following analysis, made at the Bureau of Standards in 1925, shows its chemical composition:

	Per cent
Silica (SiO_2)	0.46
Iron oxide (Fe_2O_3)	.05
Aluminum oxide (Al_2O_3)	.09
Calcium oxide (CaO)	55.72
Magnesium oxide (MgO)	.12
Carbon dioxide (CO_2)	43.40
Moisture (at 105° C.)	.07
Total	99.91

Quarrying methods were employed originally in winning the stone, but a drift mine has been in operation for a few years. The deposit of stone is about 30 feet in thickness, overlain with flint and underlain with soapstone. The room-and-pillar method of working the mine is employed with two benches. The first bench is about 16 feet and the second 14 feet. The drilling is done by compressed air and the blasting with 35 per cent dynamite. The large pieces are "pop shot" and loaded by hand into 5-ton capacity bottom dump cars which are transported to a gyratory crusher by an electric locomotive. Here the stone is reduced to pieces 6 inches in diameter or less, which are elevated to the top of the kilns by a skip hoist.

The most modern kiln equipment consists of two modified Schmatolla kilns, but there are also three pot kilns available, which are used in emergencies only. These latter kilns will not be included in this discussion.

The two modified Schmatolla kilns are about 70 feet in height with an outside shell diameter of 20 feet. The shell is steel and the lining fire brick backed up with common brick. The preheating zone is circular in cross section, 18½ feet in diameter and 25 feet in height, drawn together at the bottom. The burning zone is divided into two sections by a wall about 12 feet in height. Each section is about 12 by 5 feet, rectangular cross section but rounded at the ends. At the bottom of the wall are located 4 gas ports, 2 on each side. There are also 2 gas ports on the 12-foot side of each outer wall, making four gas ports for each section or 8 for the kiln. Above the dividing wall the cross section is circular, about

18 feet in diameter, being contracted to connect with the storage or preheating zone. The preheating zone is contracted somewhat at the bottom. Three gas producers burning washed, one-half inch, Indiana coal, are operated in connection with the 2 kilns, 2 being used for 1 of the kilns and 1 for the other. The 2 kilns average about 60 tons of quicklime each per day with a fuel ratio in excess of 4 pounds of quicklime to 1 pound of coal.

The lime is drawn continuously by an automatic contrivance from four openings in the bottom of each kiln on to belt conveyors. While it is rare for the kilns to arch, when this does occur bars are inserted in openings at the draw gates and the lime loosened. The lime as it comes from the bottoms of the kilns is sufficiently cold to be handled with the bare hands. The belt conveyors from the kiln openings discharge on to another belt conveyor which delivers the lime upon a one-half inch grid.

The material larger than the openings falls to the warehouse floor. That passing through the grid is further separated. The very fine material goes to a bin from which it is drawn and sold for agricultural purposes, while the relatively coarse product goes to a bin which supplies the hydrate plant. The lump lime is sorted to eliminate any core or overburned material, after which it is loaded by hand into barrows which are discharged into a gyratory crusher and reduced to one-half inch or less. The crushed lime is elevated to a bin which discharges to a hand bagger where it is sacked and disposed of as chemical quicklime.

The material for hydration is drawn from the storage bin, loaded into standard gauge railway cars, and transported to the hydrate plant—about 1,000 feet distant. On reaching the hydrate plant the line if rather coarse, is put through a gyratory crusher before being elevated to the hydrator bin. If it is finely divided the crusher treatment is omitted. The hydrator bin feeds two Clyde hydrators. From the hydrators the product goes to bins from which it is fed to one 4-spout Bates automatic packer.

In 1925 an installation of a 60 by 6 foot rotary kiln was being made. It was to be located inside the mine and was to be used to burn the spalls, using pulverized coal as fuel.

While about 120 tons of lime are burned the major operation of this company at this location is the production of crushed rock. Two plants are operated for this purpose, but no visit was made to them.

(h) PEERLESS WHITE LIME CO., STE. GENEVIEVE, MO.

The plant of the Peerless White Lime Co. is located on the Missouri–Illinois Railroad, 2 miles west of Ste. Genevieve, Ste. Genevieve Co., Mo.

The topography of this district is shown by the map of Weingarten quadrangle of the United States Geological Survey, 1907. The ground rises to form a hill on the south bank of Gabouri Creek. The main body of this hill appears to be limestone of compact and crystalline structure. Two strata of rock, one light gray in color and about 30 feet thick and the other almost pure white approximating 20 feet in thickness, are worked. Representative samples analyzed at the Bureau of Standards in 1926 indicated the following compositions:

	Gray	White
	Per cent	*Per cent*
Silica (SiO_2)	0.2	1.6
Iron (Fe_2O_3)	.03	.08
Alumina (Al_2O_3)	.01	.02
Lime (CaO)	55.7	53.3
Magnesia (MgO)	.2	1.6
Moisture (105° C.)	.02	.03
Carbon dioxide (CO_2)	43.4	43.7
Total	99.56	100.33

Until about 1922 a quarry was worked, but a drift mine has been opened recently through the old quarry face. The mine is electrically lighted, is worked by the usual room and pillar system with 16-foot headings and 34-foot stopes. Compressed air is used to drill the rock and 25 per cent dynamite for blasting. The large pieces after being brought down to the floor of the mine are "pop shot" to break them up so as to be handled. The "shot rock" is loaded by hand into 1¼-ton capacity boxes. After the cars, each carrying two boxes, are loaded they are transported by locomotive to the foot of an incline at the mine entrance. A cable is attached to the cars at the foot of the incline and they are hoisted to storage tracks at the foot of another incline up which they are hauled by cable to the top of the kilns.

The kilns are eight in number with outside dimensions of 14 feet diameter and 55 feet height. The shells are steel and the linings fire brick. They are 42 feet from firing floor to top and have burning zones elliptical in cross section, 5 by 9 feet. They are drawn every four hours through shears and have an output of 20 tons per day each. Seven of the kilns are gas fired, while one is direct hand fired. Each of the gas-fired kilns is supplied by two gas producers burning 2½-inch southern Illinois coal. Two gas ports are located on each of the 9-foot sides of the kilns. Air for the combustion is mixed with the gas before it enters the kilns. Steam from a 1-inch line is introduced into the kilns, creating a forced draft.

The lime is drawn into buggies which are emptied on the warehouse floor where the lime is sorted. The lime for hydration is reduced in a small Sturtevant gyratory crusher to 1 inch or less, after which it is elevated to a 40-ton capacity steel storage bin which delivers by gravity to a Kritzer hydrator. After being discharged by the hydrator the product is put through a Raymond impact mill. The fine material goes to a 4-spout Bates automatic bagger while the rejects are discarded. The compositions of the quicklime and hydrated lime are shown by the following analyses:

	Quicklime, Bureau of Standards, 1926	Hydrated lime, Bureau of Standards, 1926
	Per cent	*Per cent*
Silica, iron and aluminum oxides (SiO_2, R_2O_3)	0.16	----------
Lime (CaO)	97.72	73.94
Magnesia (MgO)	.36	.68
Loss on ignition	1.33	24.51
Carbon dioxide (CO_2)	(1)	1.04
Total	99.57	100.17

---

[1] Included in loss on ignition.

A crushing plant containing a coke-fired drier, a hammer mill, and a 6 by 12 foot wind-swept tube mill is also operated by this company. Spalls from the mine are utilized and the output is about 100 tons per day of material, 85 per cent of which will pass a No. 200 sieve. It is bagged by hand.

In 1925 two new 70-foot gas-fired kilns were in the process of erection, which it is estimated will increase the quicklime production 80 tons per day.

(i) ALLWOOD LIME CO., ROCKWOOD, WIS.

The plant of the Allwood Lime Co. is located at Rockwood, Manitowoc County, Wis., 7½ miles northwest of Manitowoc, where the offices of the company are maintained. The Chicago & North Western Railway has a switch at the plant.

The company owns at this location about 150 acres of land, all of which is believed underlaid with rock of value. An open quarry, adjacent to the plant, with a face of about 30 feet is worked. The stone is compact, crystalline, and fossiliferous, lies in ledges which are nearly horizontal with the surface of the ground and from the following analyses made at the Bureau of Standards the composition of the several strata may be seen. The names of the ledges correspond to the grade of lime made therefrom.

	Milk of magnesia No. 1	Milk of magnesia No. 2	Horologic	Vienna	Building
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Silica (SiO_2)	0.78	0.38	0.16	0.14	0.80
Iron (Fe_2O_3)	.05	.07	.04	.05	.09
Alumina (Al_2O_3)	.13	.19	.18	.21	.11
Lime (CaO_2)	39.82	39.66	31.02	30.74	30.88
Magnesia (MgO)	21.47	21.50	21.57	21.47	21.40
Carbon dioxide (CO_2)	46.90	47.18	47.02	47.10	46.84
Moisture (105° C.)	.16	.04	.02	.05	.05
Total	100.31	100.02	100.01	99.76	100.17

The overburden is slight and for its removal plow and scraper are used. The rock is drilled with well diggers and is blasted down with 35 per cent dynamite. It is further reduced by "pop shooting," the holes being drilled with air drills. Inasmuch as the several ledges of rock are burned in separate kilns for the production of different grades of lime it is necessary to sort the stone in the quarry. This is done by hand, after which the stone is loaded in like manner into 1-cubic-yard capacity, side dump, narrow gauge cars which are pulled to the foot of an incline by mules. Here the cars are attached to a cable and drawn to the top of the kilns.

The kilns are four in number. The outside dimensions are 20 feet by 20 feet by 50 feet high. They are open at the top. The casings are of limestone and the linings of fire brick. The inside cross sections are rectangular in shape, 8 by 6 feet and the fire boxes are located on two opposite sides of the kilns. The fuel is hemlock wood which is sprinkled slightly before being used, it having been found that this produces a cooler flame. About one-half cord of wood is required per ton of lime. The lime is drawn every four hours and the output is about 12 tons per kiln per day.

The quicklime is drawn into buggies after which it is sorted, any core or overburned lime being discarded. It is then ready to be "drummed." However, if it is "milk of magnesia" or "vienna" lime, it is first reduced in a Sturtevant gyratory crusher, after which it is hand packed in cans of 50, 200, or 250 pounds each.

This plant makes only a small amount of hydrated lime. The buggies containing quicklime are discharged into a Sturtevant gyratory crusher. The crushed lime is elevated to a bin from which it is fed either to a 24-inch buhr mill or to a Clyde hydrator. If the latter course is followed the hydrate is passed through a Raymond mill before being elevated to the packing bin. The hydrated lime is packed by a 2-spout Bates automatic bagger.

Power for the operation of two 35-horsepower motors is drawn from the city lines. One motor drives the hoist which carries the cars up the incline from the quarry to the top of the kilns and for the air compressor, and the second motor drives the mill machinery.

The output of this plant is about 50 tons per day, 75 per cent of which is building lime, 15 per cent milk neutralization lime, 5 per cent vienna lime and the remainder horologic, polishing, and lime for use in making lime water for hospital use.

It is of interest to note that in 1925 a small gas-fired kiln for experimental purposes was being erected.

3. SPECIFICATIONS FOR QUICKLIME AND HYDRATED LIME FOR STRUCTURAL PURPOSES

Standard Specifications of the American Society for Testing Materials for Quicklime for Structural Purposes (serial designation: C5–26)

(a) REQUIREMENTS

1. Requirements.—The quickline shall conform to the following requirements as to chemical composition, calculated to the nonvolatile basis:

	Calcium lime	Magnesium lime
	Per cent	*Per cent*
Calcium oxide, minimum	75	----------
Magnesium oxide, minimum	----------	20
Calcium and magnesium oxides, minimum	95	95
Silica, alumina, and oxide of iron, maximum	5	5
Carbon dioxide, maximum:		
(*a*) If sample is taken at the kiln	3	3
(*b*) If sample is taken at any other place	10	10

2. Percentage of Residue.—When tested in accordance with the method described in section 4, quicklime shall contain not more than 15 per cent by weight of residue.

(b) METHODS OF TEST

3. Chemical Analysis.—The chemical analysis of the lime shall be made in accordance with the Tentative Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (Serial Designation C25–26T) of the American Society for Testing Materials.[4]

4. Percentage of Residue.—An average 2½ kg (5-pound) sample shall be put in a box of wood or of some material of similarly low thermal conductivity and slaked by an experienced operator with sufficient water at 70 to 80° F. (21 to 27° C.) to produce the maximum quantity of lime putty, care being taken to avoid "burning" or "drowning" the lime. It shall be allowed to stand for one hour and then washed through a No. 20 sieve by a stream of water having a moderate pressure. No material shall be rubbed through the sieve. The washing shall be continued until the residue on the screen appears to consist wholly of coarse particles, but in no case shall washing be continued more than 30 minutes. The residue shall be dried to constant weight at a temperature of 212 to 225° F. (100 to 107° C.). The sample of lump lime taken for this test shall be broken so as to all pass a 1-inch ring and be retained on a ¼ inch sieve. Pulverized lime shall be tested as received.

(c) SAMPLING, RETESTING, PACKING, AND MARKING

5. Sampling, Retesting, Packing, Marking.—The sampling, retesting, packing, and marking shall be conducted in accordance with the Tentative Methods of Sampling, Inspection, Packing, and Marking of Quicklime and Lime Products (Serial Designation: C50–24T) of the American Society for Testing Materials.[5]

(d) APPENDIX

Quicklime can never be used as such for structural purposes; it must always be slaked first. Since the method of slaking is an important factor in determining the quality of the finished product, the following directions are given, not as a part of the specifications, but as information for the further protection of the purchaser.

---

[4] Proceedings, Am. Soc. Testing Mats., **26,** Pt. I; 1926; also 1926 Book of A. S. T. M. Tentative Standards.

[5] Proceedings, Am. Soc. Testing Mats., **24,** Pt. I, p. 844; 1924; also 1926 Book of A. S. T. M. Tentative Standards.

(e) PREPARATION OF LIME PUTTY

1. Directions for Slaking.—(*a*) *Introduction.*—Different kinds of lime vary considerably in the way in which they behave with water. A little supervision over the operation of slaking will amply pay for itself by insuring the production of the greatest possible quantity and the best possible quality of putty. To find out how to slake a new lot of lime, it is safest to try a little of it and see how it works. Since different lots of the same brand of lime vary somewhat, and since the weather conditions at the time have a decided influence, it is wise to try a sample from each lot used, whether familiar with the brand or not.

(*b*) *Classification of limes.*—In a bucket, put two or three lumps of lime about the size of one's fist, or, in the case of granular lime, an equivalent amount. Add enough water to just barely cover the lime, and note how long it takes for slaking to begin. Slaking has begun when pieces split off from the lumps or when the lumps crumble. Water of the same temperature should be used for test and field practice.

If slaking begins in less than 5 minutes, the lime is quick slaking; from 5 to 30 minutes, medium slaking; over 30 minutes, slow slaking.

(*c*) *Directions for slaking.*—For quick-slaking lime, always add the lime to the water, not the water to the lime. Have enough water at first to cover all the lime completely. Have a plentiful supply of water available for immediate use—a hose throwing a good stream, if possible. Watch the lime constantly. At the slightest appearance of escaping steam, hoe thoroughly and quickly, and add enough water to stop the steaming. Do not be afraid of using too much water with this kind of lime.

For medium-slaking lime, add the water to the lime. Add enough water so that the lime is about half submerged. Hoe occasionally if steam starts to escape. Add a little water now and then if necessary to prevent the putty from becoming dry and crumbly. Be careful not to add any more water than required, and not too much at a time.

2. Preparation of Putty for Use.—(*a*) *White coat.*—After the action has ceased, run off the putty through a No. 10 sieve and store for a minimum of two weeks.

(*b*) *Base coats.*—After the action has ceased, run off the putty through a No. 8 sieve. Add sand up to equal parts by weight, all of the hair required, and store for a minimum of two weeks.

(*c*) *Mason's mortar.*—After the action has ceased, add part or all of the sand required, and store for a minimum of 24 hours.

For slow-slaking lime, add enough water to the lime to moisten it thoroughly. Let it stand until the reaction has started. Cautiously add more water, a little at a time, taking care that the mass is not cooled by the fresh water. Do not hoe until the slaking is practically complete. If the weather is very cold, it is preferable to use hot water, but if this is not available, the mortar box may be covered in some way to keep the heat in.

Standard Specifications of the American Society for Testing Materials for Hydrated Lime for Structural Purposes (serial designation: C6–24)

1. Material Covered.—These specifications cover two classes of hydrated lime, namely, masons' hydrate and finishing hydrate.

2. Uses.—(*a*) Masons' hydrated lime may be used for scratch or brown coat of plaster, for stucco, for mortar, and for addition to Portland-cement concrete.

(*b*) Finishing hydrated lime may be used for any of the purposes enumerated in paragraph (*a*) for masons' hydrated lime, and in addition it may be used as an ingredient in the final or white coat of plaster.

(f) REQUIREMENTS

3. Masons' Hydrate.—Masons' hydrated lime shall conform to the chemical and physical requirements herein specified except that for plasticity, specified in section 8.

4. Finishing Hydrate.—Finishing hydrated lime shall conform to all chemical and physical requirements herein specified, including that for plasticity, specified in section 8.

5. Chemical Properties.—(*a*) *Carbon dioxide.*—Carbon dioxide in the sample shall not exceed 5 per cent if the sample is taken at the place of manufacture or 7 per cent if the sample is taken at any other place. The percentages in both cases are based on the nonvolatile portion. See section 9.

(*b*) *Calcium and magnesium oxides.*—Calcium and magnesium oxides shall constitute not less than 95 per cent of the nonvolatile portion. See section 9.

6. Fineness.—The sample shall leave a residue of not more than 0.5 per cent on a No. 30 sieve, and not more than 15 per cent on a No. 200 sieve. See section 10.

7. Soundness.—If the steam has no visible effect on the pat (see section 11) the sample shall be reported as being "sound." If the pat disintegrates, the sample shall be reported as being unsound, and the shipment rejected. If the pat cracks, pops, or shows other minor defects it shall not be reported as either sound or unsound, but its behavior shall be noted. Plasticity.

8. Finishing hydrated lime shall have a plasticity figure of not less than 200. See section 13.

(g) METHODS OF TEST

9. Chemical Analysis.—The chemical analysis of the hydrated lime shall be made in accordance with the Tentative Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (serial designation: C25–22T) of the American Society for Testing Materials.[6]

10. Fineness.—Fineness of hydrated lime shall be determined as follows: One hundred grams of the sample as received shall be placed on a No. 30 sieve, which shall be nested above a No. 200 sieve. The material shall be washed by means of a stream of water from a faucet. The washing shall be continued until the water coming through the sieve is clear, but in no case should the washing be continued for more than 30 minutes. The residues on both sieves shall be dried to constant weight in an atmosphere free from carbon dioxide at a temperature between 100 and and 120° C. The weights shall be calculated to percentages of the original sample, the weight of the material retained on the No. 30 sieve being added to the weight of the material retained on the No. 200 sieve to obtain the correct weight of the material retained on the No. 200 sieve.

The sieves used shall meet the requirements given in the United States Standard Sieve Series.[7]

A piece of rubber tubing attached to a water faucet is to be used for the washing. The velocity of the water may be increased by pinching the tubing, but should not be sufficient to cause any splashing of the sample over the sides of the sieve.

Care must be taken not to let water accumulate on the No. 200 sieve, else the openings will become clogged and the operation can not be completed in 30 minutes.

11. *Constancy of Volume.*—Constancy of volume shall be determined as follows: To 20 g of the sample, 100 g of standard Ottawa sand shall be added, mixed thoroughly and enough water added to the mixture to make a good plastic mortar of rather dry consistency. This shall be spread on a clean, glass plate to form a layer about one-fourth inch thick by 4 inches square. The pat shall be of even thickness throughout, and not tapering at the edges. If the mortar is too dry to work well, more water may be added. The pat shall be placed in a closet for 24 hours. The temperature in the closet shall be between 65 and 75° F. (18 and 24° C.), and there shall be free circulation of air, but no direct draft striking the pat. The pat shall then be soaked in water until a film of water stands unabsorbed on the surface of the pat. If the pat has cracked, the consistency of the mortar was too wet and a new pat must be made. Two or three pats made at the same time from mortars of slightly different consistencies will avoid delays.

Twenty grams of the sample shall be mixed with enough water to form a thick cream. This shall be spread in a thin layer on the surface of the pat. It shall be allowed to stand for 15 minutes to permit air bubbles to form. It shall be troweled to an even surface, making this skim coat as thin as possible without allowing the sand to show through. The pat shall be put in the closet, under the conditions specified above, for 24 hours. It shall be examined carefully to see that there are

---

[6] Proceedings, Am. Soc. Testing Mats., 22, P. I, p. 715; 1922.

[7] For detailed specifications for these sieves, see United States Bureau of Standards Letter Circular No. 74.

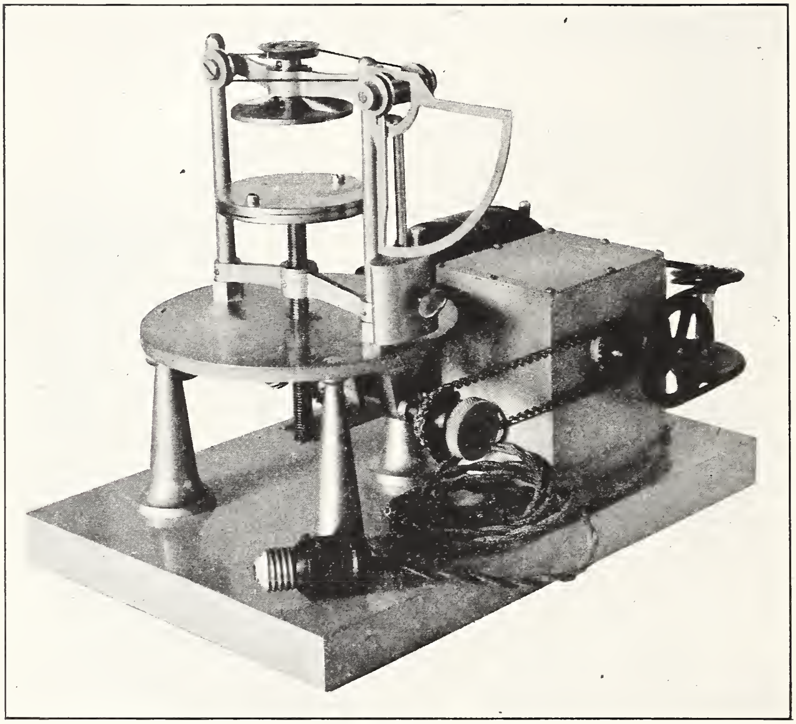

Fig. 21.—*Plasticimeter for measuring plasticity of hydrated lime*

Constants of the instrument:
- Total absorption of porcelain base plate (not shown): 20 to 25 per cent
- Rate of absorption of base plate over area $2\frac{3}{4}$ inches in diameter: 7 cc per minute for first 5 minutes
- Dimensions of base plate: 1 inch thick, 4 inches in diameter
- Dimensions of disk: $\frac{1}{32}$-inch thick, 3 inches in diameter
- Speed of vertical shaft: one revolution in 6 minutes, 40 seconds
- Upward movement of base plate: $\frac{1}{13}$-inch per revolution
- Torque on disk when bob reading is 100: 14,400 gr. cm.

no cracks or pops. The pat shall be suspended in a vessel partially filled with cold water, in such a way that the water can boil without touching the pat. The water shall be brought gradually to boiling and kept boiling gently for five hours, the pat being surrounded by steam during this time. The water shall then be permitted to cool for at least 12 hours. The pat shall then be removed and examined.

12. Consistency.—Consistency of lime putty shall be measured as follows: The lime shall be made into a stiff putty with water and permitted to soak over night. It shall be molded in a rubber ring such as is used with a Vicat needle, resting the specimen on a glass plate.

The needle used is a modified form of Vicat needle, 12.5 mm in diameter and weighing 30 g. This may conveniently be made from a suitable piece of aluminum tubing. The lower end should be closed without shoulders or curvature, and the tube loaded with shot to the specified weight. It is mounted in the Vicat needle stand.

The initial reading shall be taken with the bottom of the needle in contact with the surface of the sample. The final reading shall be taken 30 seconds after the plunger is released. A penetration of 20 mm shall be considered standard.

If the penetration is less than standard, the sample may be removed from the mold, mixed with more water, and retested. If the penetration is more than standard, the sample shall be discarded and a new one prepared.

The rubber ring and the Vicat needle stand are described in the Standard Specifications and Tests for Portland Cement (serial designation: C 9) of the American Society for Testing Materials.

13. Plasticity.—Plasticity shall be determined by means of the apparatus shown in Figure 21 as follows: Three hundred grams of the sample shall be mixed with enough water to form a thick putty. After aging in a vessel covered with a damp cloth for not less than 16 nor more than 24 hours, this putty shall be adjusted to standard consistency, as defined in section 12, with a permissible variation of ±5 mm.

A rubber ring, such as is referred to in section 12, shall be lubricated with a thin film of water, placed on a porcelain base plate, filled with the paste and struck off level. The mold shall be removed by raising it vertically without distorting the paste. The base plate and paste shall be placed in the instrument and the carriage turned up by hand until the surface of the paste is in contact with the disk and the distance between the disk and the top of the base plate is 1¼ inches.

The carriage shall be thrown into gear and the motor started. It is essential that the motor shall be started exactly 120 seconds after the first portion of the paste has been put in the mold. The time when the first portion of paste is put in the mold shall be recorded as zero time—the motor is therefore started at two minutes. Care shall be taken to protect the specimen from drafts during the test. The scale reading shall be recorded every minute until the test is completed.

The test shall be considered complete when (*a*) the scale reading reaches 100, (*b*) any reading is less than one before, or (*c*) the scale reading remains constant for three consecutive readings (two minutes) and the specimen has visibly ruptured or broken loose from the base plate.

The time and the scale reading at the end of the experiment shall be noted. The plasticity figure shall be calculated from the formula

$$P=\sqrt{F^2+(10T)^2}$$

in which P is the plasticity figure, F is the scale reading at the end of the experiment, and T is the time in minutes from when the first portion of paste was put in the mold to the end of the experiment.

After each test, the porcelain base plate shall be washed with hot water, treated with dilute hydrochloric acid to remove any lime from the surface pores, washed again with water to remove the acid, dried by heating above 100° C., and cooled to room temperature before it is used again.

(i) SAMPLING, INSPECTION, REJECTION, ETC.

14. Sampling, Retesting, Packing, Marking.—The sampling, retesting packing and marking shall be conducted in accordance with the Tentative Methods of Sampling, Inspection, Packing, and Marking of Quicklime and Lime Products (serial designation: C50—24T) of the American Society for Testing Materials.[8]

4. METHODS FOR THE DETERMINATION OF "AVAILABLE" CALCIUM OXIDE OR "AVAILABLE" CALCIUM HYDROXIDE[9]

Weigh 1.40 g of quicklime or 1.85 g of hydrated lime which has been carefully prepared and finely ground (passing a No. 100 sieve). Place in a 250 cc beaker, add 200 cc of hot water, cover, heat carefully, and then boil for three minutes.

Cool, wash down cover, add two drops of phenolphthalein, and titrate with half-normal hydrochloric acid, adding the acid as rapidly as possible dropwise, stirring vigorously to avoid local excess of acid. When white spots appear, retard the rate of addition of acid somewhat, but continue until the pink color fades out throughout the solution for a second or two. Note the reading and ignore the return of color.

Repeat the procedure of paragraph 1 above, using (instead of the beaker) a one-half liter graduated flask carrying a one-hole stopper fitted with a short glass tube drawn out to a point, with the smaller end open and upward. Cool, add dropwise 5 cc less acid than before, stirring vigorously. Call the number of cc used "A." Grind up any small lumps with a glass rod slightly flattened at one end, dilute to the mark with distilled water, stopper, mix thoroughly for four or five minutes, and let settle for half an hour.

Pipette a 200 cc portion, add phenolphthalein and titrate slowly with half-normal hydrochloric acid until colorless on standing one minute. Call this additional number of cc "B." The per cent of available calcium oxide in quicklime or of available calcium hydroxide in hydrated lime is $A + 2.5\,B$.

---

[8] Proceedings, Am. Soc. Testing Mats., 24, Pt. I; 1924.

[9] Bureau of Standards Circular No. 231, "Recommended Specification for Quicklime and Hydrated Lime for Use in the Purification of Water."

Washington, July 3, 1926.

⁂