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CEMENTS, LIMES, AND PLASTERS

THEIR MATERIALS, MANUFACTURE, AND PROPERTIES

BY

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PREFACE.

Of all the non-metallic structural materials in use by the engineer, the most important at the present day are those included under the head of Cementing Materials, using that term in its broadest sense to include not only the hydraulic cements proper, but the limes, plasters, and allied materials. This importance is due in large part to the advances which have been made, in American practice, in the methods of manufacturing these products, for these advances in technology have resulted in supplying the engineer with uniform and high-grade cementing materials at prices low enough to permit of great increase in their uses.

In consequence of this growth of the industries based on cementing materials an extensive literature on the subject has developed. This literature is, however, widely scattered through the pages of many technical and scientific journals and transactions, and no adequate summary of the matter from an American point of view has yet appeared. The present volume is the result of an attempt to provide such a summary, covering the composition and character of the raw materials, the methods of manufacture, and the properties of the various cementing materials.

In a work of this scope many points of interest can only be suggested, not discussed in detail. For the convenience of those who wish to make further studies of such subjects, very complete reference lists have been placed in almost every chapter of this volume. These lists necessarily contain the names of some papers and articles published in European periodicals or transactions, but most of the titles cited will be found to be from readily accessible American journals. A working engineer rarely has at his command an extensive technical library, so that references to the proceedings of some German scientific society are apt to prove a vexation rather than an aid.

Stress has been laid, in the discussion of manufacturing methods, on the general chemical and physical principles which underlie these methods rather on the details which differ at every plant and may change with every year. So far as possible, however, such details as bear on labor, power, and costs have been carefully discussed, and it is believed that the estimates furnished are entirely reliable.

The writer's acknowledgments are due to *Engineering News, Municipal Engineering, Engineering Record, Engineering and Mining Journal, Cement*, and *The Iron Age* for permission to use illustrations and to reprint parts of articles which had appeared first in their columns. To an even greater extent he is indebted to the chemists and managers of American cement-, lime-, and plaster-plants, and to manufacturers of different lines of machinery, for data and illustrations which they have kindly furnished for use in this volume.

It may not be out of place to state that this volume was planned and partly written in 1901. If it had been published at that date the words "probably" and "possibly" would not have occurred so frequently as they do in the present work, for at that time the writer felt a cheerful certainty in regard to many points which now seem less obvious. A wider personal experience, taken in connection with the remarkable changes which have recently affected both the theory and practice of cement-manufacture, has resulted in a more cautious treatment of certain phases of the subject.

WASHINGTON, D. C., March 6, 1905. EDWIN C. ECKEL.

TABLE OF CONTENTS.

INTRODUCTION.

PART I. PLASTERS.

CHAPTER I.

COMPOSITION, DISTRIBUTION, AND EXCAVATION OF GYPSUM.

CHAPTER IV.

FLOORING-PLASTERS AND HARD-FINISH PLASTERS.

CHAPTER V.

STATISTICS OF THE GYPSUM AND PLASTER INDUSTRIES.

PART II. LIMES.

CHAPTER VI.

COMPOSITION, ORIGIN, AND GENERAL CHARACTERS OF LIMESTONES.

CHAPTER VII.

LIME-BURNING.

CHAPTER VIII.

COMPOSITION AND PROPERTIES OF LIME.

CHAPTER IX.

HYDRATED LIME: ITS PREPARATION AND PROPERTIES.

CHAPTER X.

MANUFACTURE AND PROPERTIES OF LIME-SAND BRICKS.

PART III. MAGNESIA AND OXYCHLORIDE CEMENTS.

CHAPTER XI.

SOURCES AND PREPARATION OF MAGNESIA.

CHAPTER XII.

MAGNESIA BRICKS AND OXYCHLORIDE CEMENTS.

PART IV. HYDRAULIC LIMES, SELENITIC LIMES, AND GRAPPIER CEMENTS.

CHAPTER XIII.

THE THEORY OF HYDRAULIC LIMES.

CHAPTER XIV.

EMINENTLY HYDRAULIC LIMES: GRAPPIER CEMENTS.

CHAPTER XV.

FEEBLY HYDRAULIC LIMES: SELENITIC LIMES.

PART V. NATURAL CEMENTS.

CHAPTER XVI.

DEFINITION AND RELATIONS OF NATURAL CEMENTS.

CHAPTER XVII.

RAW MATERIAL: NATURAL-CEMENT ROCK.

CHAPTER XVIII.

MANUFACTURE OF NATURAL CEMENTS.

CHAPTER XIX.

COMPOSITION AND PROPERTIES OF NATURAL CEMENTS.

CHAPTER XX.

SPECIFICATIONS FOR NATURAL CEMENTS.

CHAPTER XXI.

HISTORY, STATISTICS AND PROSPECTS OF THE NATURAL-CEMENT INDUSTRY.

PART VI. PORTLAND CEMENT.

CHAPTER XXII.

PORTLAND CEMENT: PRELIMINARY STATEMENTS.

CHAPTER XXIII.

LIMESTONES.

CHAPTER XXIV.

ARGILLACEOUS LIMESTONE: CEMENT ROCK.

CHAPTER XXV.

FRESH-WATER MARLS.

CHAPTER XXVI.

ALKALI WASTE: BLAST-FURNACE SLAG.

CHAPTER XXVII.

CLAYS, SHALES, AND SLATES.

CHAPTER XXVIII.

EXCAVATING THE RAW MATERIALS.

CHAPTER XXIX.

CALCULATION AND CONTROL OF THE MIX.

CHAPTER XXX.

PREPARING THE MIXTURE FOR THE KILN.

CHAPTER XXXV.

STANDARD TYPES OF CRUSHING AND PULVERIZING MACHINERY.

CHAPTER XXXII.

CEMENT BURNING: FIXED KILNS.

CHAPTER XXXIII.

THE ROTARY KILN.

CHAPTER XXXIV.

HEAT CONSUMPTION AND HEAT UTILIZATION.

CHAPTER XXXV.

REQUISITES AND TREATMENT OF KILN FUELS.

CHAPTER XXXVI.

CLINKER COOLING, GRINDING, AND STORAGE. USE OF GYPSUM.

CHAPTER XXXVII.

COSTS AND STATISTICS.

CHAPTER XXXVIII.

CONSTITUTION, SETTING, PROPERTIES, AND COMPOSITION.

CHAPTER XXXIX.

PHYSICAL PROPERTIES. TESTING METHODS.

CHAPTER XL.

SPECIFICATIONS FOR PORTLAND CEMENT.

PART VII. PUZZOLAN CEMENTS.

CHAPTER XLI.

PUZZOLANIC MATERIALS IN GENERAL.

CHAPTER XLII.

SLAG CEMENT: REQUISITES AND TREATMENT OF THE SLAG.

CHAPTER XLIII.

SLAG CEMENT: LIME, MIXING, AND GRINDING.

CHAPTER XLIV.

SLAG CEMENT: COMPOSITION AND PROPERTIES.

CHAPTER XLV.

SLAG BRICKS AND SLAG BLOCKS.

LIST OF ILLUSTRATIONS.

LIST OF TABLES.

CEMENTS, LIMES, AND PLASTERS.

INTRODUCTION.

Few economic movements, during the past decade, have equaled in importance or interest the marvelous growth of the industries based on the non-metallic structural materials. In this group are included the stone used for building purposes, such clay products as are used in engineering, and, last in order but not in importance, the cementing materials. The production of structural materials in the United States for the years 1902–1903 has been summarized in the following table, for convenience of reference.

Table 1.

Production of Structural Materials, 1902–1903.

	1902.	1903.
Building stone.	$36,486,392	$36,052,376
Brick, tile, etc.	98,042,078	105,526,596
Cementing materials.	36,849,943	45,607,436
Total, structural materials. .	$171,378,413	$192,186,408

Of the three subgroups of materials quoted in the above table, the third—cementing materials—is the subject of the present volume. It will therefore be of advantage to consider the financial statistics of this subgroup in somewhat more detail. The following table (Table 2) gives the value of the production in the United States, for the years 1900–1903 inclusive, of the six classes into which the cementing materials may conveniently be divided. On later pages, where these classes are separately discussed, much more detailed statistics are given in regard to each product.

TABLE 2.

VALUE OF CEMENTING MATERIALS PRODUCED IN THE UNITED STATES, 1900–1903.

	1900.	1901.	1902.	1903.
Plaster of Paris, wall-plaster, etc.	$1,500,270	$1,325,517	$1,889,190	$3,550,390
Lime	6,970,062	8,597,030	9,573,011	10,105,190
Magnesia and magnesite	19,333	43,057	21,362	20,515
Natural cement	3,728,848	3,056,278	4,076,630	3,675,520
Portland cement	9,280,525	12,532,360	20,864,078	27,713,319
Slag cement	274,208	198,151	425,672	542,502
Total, cementing materials	$21,773,246	$25,752,393	$36,849,943	$45,607,436

It will be seen that the value of the entire group has more than doubled in these four years. Examination of the figures for each subgroup will show that this increase was by no means equally distributed. The production of Portland cement almost tripled in value from 1900 to 1903; the values of the plaster and slag-cement production about doubled; while lime increased only 50 per cent, and magnesia and the natural cements were practically stationary.

The great advance in value of the cementing materials, taken as a group, has been steady and natural. Similar increases can therefore be reasonably expected to occur in future years. Individual years, however, may give less encouraging results; because any general business depression reacts sharply upon building industries first of all.

Classification and Relationships of Cementing Materials.

It seems desirable, before taking up the various classes of cement materials individually, to devote an introductory section to the consideration of the entire group of cementing materials, and to attempt to indicate briefly the relationships that exist between the different classes which compose this group.

These relationships, as regards both resemblances and differences, seem to be best brought out by the scheme of classification presented below. This classification was first published by the writer in 1902,* in a form differing but slightly from that here given. It is based primarily upon the amount of chemical change caused by the processes of manufacture and use; and secondarily upon the chemical composition of the cementing material after setting. As regard is paid to both technologic and commercial considerations, it would seem to furnish a fairly satisfactory working classification.

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* Eckel, E. C. The classification of the crystalline cements. American Geologist, vol. 29, pp. 146–154. March, 1902.

CLASSIFICATION OF CEMENTING MATERIALS.

GROUP I. SIMPLE CEMENTING MATERIALS: including all those cementing materials which are produced by the expulsion of a liquid or gas, through the action of heat, from a natural raw material, and whose setting properties are due to the simple reabsorption of the same liquid or gas, and the reassumption of original composition; the set cement being, therefore, similar in chemical composition to the raw material from which it was derived.

SUBGROUP I a. HYDRATE CEMENTING MATERIALS OR PLASTERS: manufactured by driving off water from gypsum; setting properties due to the reabsorption of water.

SUBGROUP I b. CARBONATE CEMENTING MATERIALS OR LIMES AND MAGNESIA: manufactured by driving off carbon dioxide from limestone or magnesite; setting properties due to the reabsorption of carbon dioxide.

GROUP II. COMPLEX CEMENTING MATERIALS: including all those cementing materials whose setting properties are due to the formation of entirely new chemical compounds during manufacture or use; the set cement being, therefore, different in chemical composition from the raw material or mixture of raw materials from which it was derived.

SUBGROUP II a. SILICATE CEMENTING MATERIALS OR HYDRAULIC CEMENTS: setting properties due entirely or largely to the formation of silicates during the processes of manufacture or use.

SUBGROUP II b. OXYCHLORIDE CEMENTING MATERIALS: setting properties due to the formation of oxychlorides.

The various groups and subgroups above noted will now be taken up separately and briefly described, in order that the principles on which the classification is based may be clearly understood.

Group I. Simple Cementing Materials.

The products included in the present group include those known as "plasters", "hard-finish cements", "limes", and "magnesia."

The material from which the "plasters" and "hard-finish cements" are derived is gypsum, a hydrous calcium sulphate; while the limes are derived from limestone, which is essentially calcium carbonate, though usually accompanied by greater or less amounts of magnesium carbonate; and magnesia is derived from more or less pure magnesite, a natural magnesium carbonate.

On heating gypsum to a certain temperature, the raw material parts readily with much of its water, leaving an almost anhydrous calcium sulphate, known commercially as plaster of Paris. On exposing this plaster to water, it rehydrates, and again takes the composition of the gypsum from which it was derived.

In like manner limestone, on being sufficiently heated, gives off its carbon dioxide, leaving calcium oxide, or "quicklime". This, on exposure to moisture and air carrying carbon dioxide, reabsorbs carbon dioxide and reassumes its original composition—calcium carbonate. Magnesite, on being heated, loses its carbon dioxide, leaving magnesium oxide, or magnesia. This, under normal conditions of burning, will reabsorb carbon dioxide, and set in its original form as magnesium carbonate.

The cementing materials included in this group, therefore, while differing in composition and properties, agree in certain important points. They are all manufactured by heating a natural raw material sufficiently to remove much or all of its water or carbon dioxide; and, in all, the setting properties of the cementing material are due to the fact that, on exposure to the water or carbon dioxide which has thus been driven off, the cement reabsorbs the previously expelled liquid or gas, and reassumes the chemical composition of the raw material from which it was derived. Plaster of Paris, after setting, is not chemically different from the gypsum from which it was derived; while if the sand, added simply to avoid shrinkage, be disregarded, a thoroughly hardened lime mortar is nothing more or less than an artificial limestone.

The principal points of difference between the two subgroups—the plasters and the limes—may be briefly noted as follows:

Subgroup I a. Hydrate cementing material: plasters.—The materials here included are known in commerce as "plaster of Paris", "cement plaster", "Keene's cement", "Parian cement", etc. All of these hydrate cements or plasters are based upon one raw material—gypsum. The partial dehydration of pure gypsum produces plaster of Paris. By the addition to gypsum, either by nature or during manufacture, of relatively small amounts of other materials, or by slight variations in the processes of manufacture, the time of setting, hardness, and other important technical properties of the resulting plaster can be changed to a degree sufficient to warrant separate naming and descriptions of the products.

Both the technology and the chemistry of the processes involved in the manufacture of the hydrate cements are simple. The mineral gypsum, when pure, is a hydrous sulphate of lime, of the formula $CaSO_4,2H_2O$, corresponding to the composition: calcium sulphate 79.1%, water 20.9%. As noted later (under the head of Cement Plasters) gypsum, as mined, rarely even approximates to this ideal composition, its impurities often amounting to 25% or even more. These impurities, chiefly clayey materials and fragments of quartz and limestone, often exercise an appreciable effect upon the properties of the plaster resulting from burning such impure gypsum. On burning gypsum at a relatively low temperature (350°–400° F.) much of its water of combination is driven off, leaving a partially dehydrated calcium sulphate. This, when ground, is plaster of Paris, or if it either naturally or artificially contains certain impurities, it is called "cement plaster". When either plaster of Paris or cement plaster is mixed with water, the percentage of water which was driven off during calcination is reabsorbed, and the mixture hardens, having again become a hydrous sulphate of lime. The processes involved in the manufacture and setting of the dead-burned plasters and hard-finish plasters are slightly more complicated, but the reactions involved are of the same general type.

Subgroup I b. Carbonate cementing materials: limes and magnesia.—The cementing materials falling in the present subgroup are oxides derived from natural carbonates by the application of heat. On exposure, under proper conditions, to any source of carbon dioxide, the cementing material recarbonates and "sets". In practice the carbon dioxide required for setting is obtained simply by exposure of the mortar to the air. In consequence the set of these carbonate cements, as commonly used, is very slow (owing to the small amount of carbon dioxide which can be taken up from ordinary air); and, what is more important from an engineering point of view, none of the mortar in the interior of a wall ever acquires hardness, as only the exposed portions have an opportunity to absorb carbon dioxide. From the examination of old mortars it has been thought probable that a certain amount of chemical action takes place between the sand and the lime, resulting in the formation of lime silicates; but this effect is slight and of little engineering importance compared with the hardening which occurs in consequence of the reabsorption of carbon dioxide from the air.

Limestone is the natural raw material whose calcination furnishes most of the cementing materials of this group.* If the limestone be an almost pure calcium carbonate, it will, on calcination, yield calcium oxide, or "quicklime". If, however, the limestone should contain any appreciable percentage of magnesium carbonate, the product will be a mixture of the oxides of calcium and magnesium, commercially known as a magnesian lime. A brief sketch of the mineralogic relationships of the various kinds of limestone, in connection with the

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* The subject of magnesia as a cementing material, being too complicated for brief discussion, will not be taken up here. See Chapters XI and XII.

chemistry of lime-burning, will be of service at this point of the discussion.

Pure limestone has the composition of the mineral calcite, whose formula is $CaCO_3$, corresponding to the composition: calcium oxide 56%, carbon dioxide 44%. In the magnesian limestones part of this calcium carbonate is replaced by magnesium carbonate, the resulting rock therefore having a formula of the type $XCaCO_3,YMgCO_3$. This replacement may reach the point at which the rock has the composition of the mineral dolomite—an equal mixture of the two carbonates, with the formula $CaCO_3,MgCO_3$, corresponding to the composition: calcium oxide 30.44%, magnesium oxide 21.73%, carbon dioxide 47.83%. Limestones may therefore occur with any intermediate amount of magnesium carbonate, and the lime which they produce on calcination will carry corresponding percentages of magnesium oxide, from 0% to 41.65%. Commercially those limes which carry less than 10% of magnesium oxide are, for building purposes, marketable as "pure limes"; while those carrying more than that percentage will show sufficiently different properties to necessitate being marketed as "magnesian limes".

Aside from the question of magnesia, a limestone may contain a greater or lesser amount of real impurities. Of these the most important are silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3). These impurities, if present in sufficient quantity, will materially affect the properties of the lime produced, as will be noted later under the heads of Hydraulic Limes and Natural Cements.

The limes may be divided into two classes:

(1) High-calcium limes;
(2) Magnesian limes.

High-calcium limes.—On heating a relatively pure carbonate of lime to a sufficiently high degree, its carbon dioxide is driven off, leaving calcium oxide (CaO), or "quicklime". Under ordinary conditions, the expulsion of the carbon dioxide is not perfectly effected until a temperature of 925° C. is reached. The process is greatly facilitated by blowing air through the kiln, or by the injection of steam. On treating quicklime with water, "slaking" occurs, heat being given off, and the hydrated calcium oxide (CaH_2O_2) being formed. The hydrated oxide (slaked lime) will, upon exposure to the atmosphere, slowly reabsorb sufficient carbon dioxide to reassume its original composition as lime carbonate. As this reabsorption can take place only at points where the mortar is exposed to the air, the material in the middle of thick walls never becomes recarbonated. In order to counteract the shrinkage which would otherwise take place during the drying of the mortar, sand is invariably added in the preparation of lime mortars, and, as noted above, it is possible that certain reactions take place between the lime and the sand. Such reactions, however, though possibly contributing somewhat to the hardness of old mortars, are only incidental and subsidiary to the principal cause of setting—recarbonation. The presence of impurities in the original limestone affects the character and value of the lime produced. Of these impurities, the presence of silica and alumina in sufficient quantities will give hydraulic properties to the resulting limes; such materials will be discussed in the next group as Hydraulic Limes and Natural Cements.

Magnesian limes.—The presence of any considerable amount of magnesium carbonate in the limestone from which a lime is obtained has a noticeable effect upon the character of the product. If burned at the temperature usual for a pure limestone, magnesian limestones give a lime which slakes slowly without evolving much heat, expands less in slaking, and sets more rapidly, than pure lime. To this class belong the well-known and much-used limes of Canaan (Conn.); Tuckahoe, Pleasantville, and Ossining (N. Y.); various localities in New Jersey and Ohio; and Cedar Hollow (Penn.). Under certain conditions of burning, pure magnesian limestones yield hydraulic products, but in this case, as in the case of the product obtained by burning pure magnesite, the set seems to be due in part at least to the formation of a hydroxide rather than of a carbonate. Magnesian limestones carrying sufficient silica and alumina will give, on burning, a hydraulic cement falling in the next group under the head of Natural Cements.

Group II. Complex Cementing Materials.

The cementing materials grouped here as Complex Cements include all those materials whose setting properties are due to the formation of new compounds, during manufacture or use, and not to the mere reassumption of the original composition of the material from which the cement was made. These new compounds may be formed either by chemical change during manufacture or by chemical interaction, in use, of materials which have merely been mechanically mixed during manufacture.

Subgroup II a. Silicate cementing materials: hydraulic cements.—In the class of silicate cements are included all the materials commonly known as cements by the engineer (natural cements, Portland cement, puzzolan cements), together with the hydraulic limes.

Though differing widely in raw materials, methods of manufacture, and properties, the silicate cements agree in two prominent features: they are all hydraulic (though in very different degrees); and this property of hydraulicity is, in all, due largely or entirely to the formation of tricalcic silicate ($3CaO,SiO_2$). Other silicates of lime, as well as silico aluminates, may also be formed; but they are relatively unimportant, except in certain of the natural cements and hydraulic limes, where the lime aluminates may be of greater importance than is here indicated. This will be recurred to in discussing the groups named.

The silicate cements are divisible, on technologic grounds, into four distinct classes. The basis for this division is given below. It will be seen that the last named of these classes (the puzzolan cements) differs from the other three very markedly, inasmuch as its raw materials are not calcined after mixture; while in the last three classes the raw materials are invariably calcined after mixture. The four classes differ somewhat in composition, but more markedly in methods of manufacture and in the properties of the finished cements.

CLASSES OF HYDRAULIC CEMENTS.

1. **Hydraulic limes** are produced by burning, at relatively low temperatures, a natural siliceous limestone which carries so much lime carbonate, compared to its content of silica and alumina, that the burned product will contain a considerable amount of free lime (CaO) in addition to the silicates and aluminates of lime that have been formed. In consequence of the relatively large percentage of free lime, the burned masses will slake if water be poured on them, but because much of them is composed of silicates and aluminates of lime, they will slake very slowly and their final product will have hydraulic properties.

The hydraulic limes are thus intermediate in composition, methods of manufacture, and properties between the true limes and the cements proper.

2. **Natural cements** are produced by burning a natural clayey limestone, containing from 15 to 40 per cent of silica, alumina, and iron oxide. This burning takes place at a temperature that is usually little if any above that of an ordinary lime-kiln. During the burning the carbon dioxide of the limestone is almost entirely driven off, and the lime combines with the silica, alumina, and iron oxide, forming a mass containing silicates, aluminates, and ferrites of lime. In case the original limestone contained much magnesium carbonate, the burned rock will contain a corresponding amount of magnesia and magnesian compounds.

After burning, the burned mass will not slake if water be poured on it. It is necessary, therefore, to grind it quite fine, after which, if the resulting powder (natural cement) be mixed with water, it will harden rapidly. This hardening or setting will also take place under water.

3. **Portland cement** is produced by burning a finely ground artificial mixture containing essentially lime, silica, alumina, and iron oxide, in certain definite proportions. Usually this combination is made by mixing limestone, chalk, or marl with clay or shale, in which case about three times as much of lime carbonate as of clayey materials should be present in the mixture. The burning of this mixture takes place at a high temperature, approaching 3000° F., and must therefore be carried on in kilns of special design and lining. During the burning, combination of the lime with the silica, alumina, and iron oxide takes place. The product of the burning is a semifused mass called "clinker", and consists of silicates, aluminates, and ferrites of lime, each being present in certain fairly definite proportions. This "clinker" must be finely ground. After such grinding the resulting powder, which is then Portland cement, will harden under water.

Portland cement is blue to gray in color, with a specific gravity of 3.0 to 3.2. It sets more slowly than natural cements, but soon attains a higher tensile strength.

4. **Puzzolan cements.**—Certain natural and artificial products, such as some volcanic ashes and blast-furnace slags, will show feeble hydraulic properties if finely pulverized. Their hydraulicity is very markedly increased if their powder, instead of being used alone, is mixed with powdered slaked lime. Such mixtures of slaked lime with a relatively feeble hydraulic agent are known as Puzzolan Cements. The puzzolan cements are therefore simply mechanical mixtures of the two ingredients, as the mixture is not burned at any stage of the process.

Puzzolan cements are usually light bluish in color, and of lower specific gravity and less tensile strength than Portland cement. They are better adapted to use under water than to use in air, as is explained later in this volume

Subgroup II b. Oxychloride cements.—In 1853 the chemist Sorel discovered the fact that zinc chloride mixed with zinc oxide united with it to form a very hard cement. Later it was found that a solution of magnesium chloride will unite, in the same manner, with magnesia. The product is, in both cases, an oxychloride—of zinc or magnesium as the case may be.

It is obvious that cementing materials of this character cannot well be placed on the market as structural cements, but the property above noted has been taken advantage of in the manufacture of a number of patented artificial stones, the exact methods followed depending upon the particular process that is used. The best known of these artificial stones is probably "Sorel-stone", which is frequently alluded to in engineering text-books. As the subject of oxychloride cements is intimately connected with that of magnesia cements, the two will be discussed together in Chapters XI to XII.

The following table shows the relation of the various cementing materials which have been briefly discussed in this chapter. For convenience of reference, the pages on which the different products are described in detail have been added.

Simple cements	Hydrate cements or plasters	Plaster of Paris	31–67
		Cement plasters	
		Hard-finish plasters	76–78
		Dead-burnt plasters	68–76
	Carbonate cements or limes	High-calcium limes	88–147
		Magnesian limes	
		Magnesia	148–167
Complex cements	Silicate cements	Hydraulic lime	168–193
		Natural cements	194–293
		Portland cement	294–631
		Puzzolan cements	632–689
	Oxychloride cements	Sorel-stone, etc.	162–167

Chemical and Physical Data Employed in the Discussion of Cementing Materials.

In the course of the discussion it will frequently be necessary to use certain chemical and physical data, such as atomic weights, values of various heat-units, etc. These are to be found in most engineering pocket-books, but for convenience of reference the more important data have been placed in the present chapter.

Atomic weights of elements.—In the following table (Table 3) are given the names, symbols, and atomic weights of all the chemical elements.* The first column of this table contains the name of each element; the second, its chemical symbol or abbreviation; the third, its atomic weight calculated on the basis of the atomic weight of oxygen being 16; the fourth, its atomic weight on the basis of the atomic weight of hydrogen being 1.

In use, it is a matter of absolute indifference whether the figures in

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* Through the courtesy of Prof. F. W. Clarke the writer is enabled to present this table, which contains the corrections for 1905.

the third column or those in the fourth are employed: but of course the selection should be consistent throughout. Chemists are about equally divided as to the use of the two series. For many purposes the O=16 basis is the more convenient, as it gives even figures for several common elements.

Such elements as enter into the calculation of cement, plaster, lime, fuel, or slag are given in black-faced type for convenience of reference.

TABLE 3.

ATOMIC WEIGHTS OF ELEMENTS.

Name of Element.	Symbol.	Atomic Weight.		Name of Element.	Symbol.	Atomic Weight.	
		O=16.	H=1.			O=16.	H=1.
Aluminum	**Al**	27.1	26.9	Neodymium	Nd	143.6	142.5
Antimony	Sb	120.2	119.3	Neon	Ne.	20.0	19.9
Argon	A	39.9	39.6	Nickel	Ni	58.7	58.3
Arsenic	As	75.0	74.4	**Nitrogen**	**N**	14.04	13.93
Barium	Ba	137.4	136.4	Osmium	Os	191.0	189.6
Bismuth	Bi	208.5	206.9	**Oxygen**	**O**	16.00	15.88
Boron	B	11.0	10.9	Palladium	Pd	106.5	105.7
Bromine	Br	79.96	79.36	**Phosphorus**	**P**	31.0	30.77
Cadmium	Cd	112.4	111.6	Platinum	Pt	194.8	193.3
Cæsium	Cs	132.9	131.9	**Potassium**	**K**	39.15	38.85
Calcium	**Ca**	40.1	39.7	Praseodymium	Pr	140.5	139.4
Carbon	**C**	12.0	11.91	Radium	Ra	225.0	223.3
Cerium	Ce	140.25	139.2	Rhodium	Rh	103.0	102.2
Chlorine	Cl	35.45	35.18	Rubidium	Rb	85.5	84.9
Chromium	Cr	52.1	51.7	Ruthenium	Ru	101.7	100.9
Cobalt	Co	59.0	58.57	Samarium	Sm	150.3	149.2
Columbium	Cb	94.0	93.3	Scandium	Sc	44.1	43.8
Copper	Cu	63.6	63.1	Selenium	Se	79.2	78.6
Erbium	Er	166.0	164.7	**Silicon**	**Si**	28.4	28.2
Fluorine	F	19.0	18.9	Silver	Ag	107.93	107.1
Gadolinium	Gd	156.0	154.8	**Sodium**	**Na**	23.05	22.88
Gallium	Ga	70.0	69.5	Strontium	Sr	87.6	86.94
Germanium	Ge.	72.5	72.0	**Sulphur**	**S**	32.06	31.82
Glucinum	Gl	9.1	9.03	Tantalum	Ta	183.0	181.6
Gold	Au	197.2	195.7	Tellurium	Te	127.6	126.6
Helium	He	4.0	4.0	Terbium	Tb	160.0	158.8
Hydrogen	**H**	1.008	1.000	Thallium	Tl	204.1	202.6
Indium	In	115.0	114.1	Thorium	Th	232.5	230.8
Iodine	I	126.97	126.01	Thulium	Tm	171.0	169.7
Iridium	Ir	193.0	191.5	Tin	Sn	119.0	118.1
Iron	**Fe**	55.9	55.5	**Titanium**	**Ti**	48.1	47.7
Krypton	Kr	81.8	81.2	Tungsten	W	184.0	182.6
Lanthanum	La	138.9	137.9	Uranium	U	238.5	236.7
Lead	Pb	206.9	205.35	Vanadium	V	51.2	50.8
Lithium	Li	7.03	6.98	Xenon	Xe	128.0	127.0
Magnesium	**Mg**	24.36	24.18	Ytterbium	Yb	173.0	171.7
Manganese	**Mn**	55.0	54.6	Yttrium	Yt	89.0	88.3
Mercury	Hg	200.0	198.5	Zinc	Zn	65.4	64.9
Molybdenum	Mo	96.0	95.3	Zirconium	Zr	90.6	89.9

Chemical compounds. — Certain chemical combinations will be mentioned very frequently in the discussion of cementing materials. The more important of these compounds are listed in the following table, with their symbols and also the name by which they are known when they occur as minerals or as commercial products.

TABLE 4.

NAMES AND SYMBOLS OF PRINCIPAL COMPOUNDS.

Symbol.	Name.	Mineral or Commercial Name.
CaO	Calcium oxide	Lime: quicklime
$CaCO_3$	Calcium carbonate	Calcite
$3CaO,SiO_2$	Tricalcium silicate	
$CaCO_3.MgCO_3$	Calcium-magnesium carbonate	Dolomite
CaH_2O_2	Lime hydrate	Slaked lime
$CaSO_4$	Calcium sulphate	Dead-burned plaster
$CaSO_4+2H_2O$	Hydrous calcium sulphate	Gypsum
$2CaSO_4+H_2O$		Plaster of Paris
MgO	Magnesium oxide	Magnesia
$MgCO_3$	Magnesium carbonate	Magnesite
SiO_2	Silica	Quartz
Al_2O_3	Alumina	
FeO	Ferrous oxide	
Fe_2O_3	Ferric oxide	

Heat-units.—Two heat-units are now in common use—the British and the metric.

The British thermal unit (=B.T.U.) is the quantity of heat required to raise the temperature of 1 lb. of water one degree Fahrenheit when at the temperature of maximum density (=39.1° F. or 4° C.).

The metric unit (=calorie) is the quantity of heat required to raise the temperature of 1 kilogram of water one degree centigrade when at the temperature of maximum density.

From these definitions the two units may be converted according to the following equations:

$$1 \text{ B.T.U.} = .252 \text{ calorie.}$$

$$1 \text{ calorie} = 3.968 \text{ B.T.U.}$$

$$1 \text{ calorie per kilogram} = 1.8 \text{ B.T.U per pound.}$$

Metric conversion tables.—Since much of the literature of cementing materials is published in French and German, metric units are frequently employed. In the present volume such units have been converted into American units throughout, but for convenience a few conversion tables are here inserted to cover the more common cases.

Length.

1 inch = 2.54 centimeters.
1 centimeter = .3937 inch.
1 foot = .3048 meter.
1 meter = 39.37 inches
= 3.2808 feet.

Surface.

1 square inch = 6.452 square centimeters.
1 square centimeter = .155 square inch.
1 square foot = .0929 square meter.
1 square meter = 10.764 square feet.

Volume.

1 cubic inch = 16.387 cubic centimeters.
1 cubic centimeter = .061 cubic inch.
1 cubic foot = .02832 cubic meter.
1 cubic yard = .7645 cubic meter.
1 cubic meter = 35.314 cubic feet
= 1.308 cubic yards.

Weight.

1 ounce avoirdupois = 28.35 grams.
1 pound = .4536 kilogram.
1 kilogram = 2.2046 pounds.

Capacity.

1 cubic foot = 28.317 liters.
1 liter = 61.023 cubic inches
= .03531 cubic foot.
1 gallon = 3.785 liters.

Pressure.

1 pound per square inch = .070308 kilogram per square inch.
1 kilogram per square centimeter = 14.223 pounds per square inch.

PART I. PLASTERS.

CHAPTER I.

COMPOSITION, DISTRIBUTION, AND EXCAVATION OF GYPSUM.

THE mineral called *gypsum* is the raw material which serves as the basis for the manufacture of plaster of Paris, "cement plaster", and the various related types of plasters. In the present chapter the composition, properties, varieties, mode of occurrence, origin, and distribution of gypsum will be described in the order named, after which the methods and costs of quarrying and mining gypsum will be discussed

Chemical composition.—The mineral gypsum, when absolutely pure is a hydrous sulphate of lime, made up of one molecule of lime sulphate combined with two molecules of water. The chemical formula o gypsum is therefore $CaSO_4+2H_2O$. This, when reduced to percentages of weight, corresponds to the following:

$$\text{Gypsum } (CaSO_4+2H_2O)=\begin{cases}\text{Lime sulphate } (CaSO_4)\ldots\ldots & 79.1\% \\ \text{Water } (H_2O)\ldots\ldots\ldots\ldots\ldots & 20.9\end{cases}$$

The 79.1% of lime sulphate can, in turn, be considered as being made up of 32.6% of lime (CaO), plus 46.5% of sulphur trioxide (SO_3) Reduced to its ultimate components, the composition of pure gypsum may therefore be represented as follows:

$$\text{Gypsum } (CaSO_4+2H_2O)=\begin{cases}\text{Lime } (CaO)\ldots\ldots\ldots\ldots\ldots & 32.6\% \\ \text{Sulphur trioxide } (SO_3)\ldots\ldots & 46.5 \\ \text{Water } (H_2O)\ldots\ldots\ldots\ldots\ldots & 20.9 \\ & \overline{100.0}\end{cases}$$

Deposits of gypsum large enough to be worked for plaster are, however, rarely even approximately as pure as this. Gypsum as excavated for a plaster-plant will usually carry varying and often high percentages of such impurities as clay, limestone, magnesian limestone, iron oxide

L.L. POATES ENGR., N.Y.

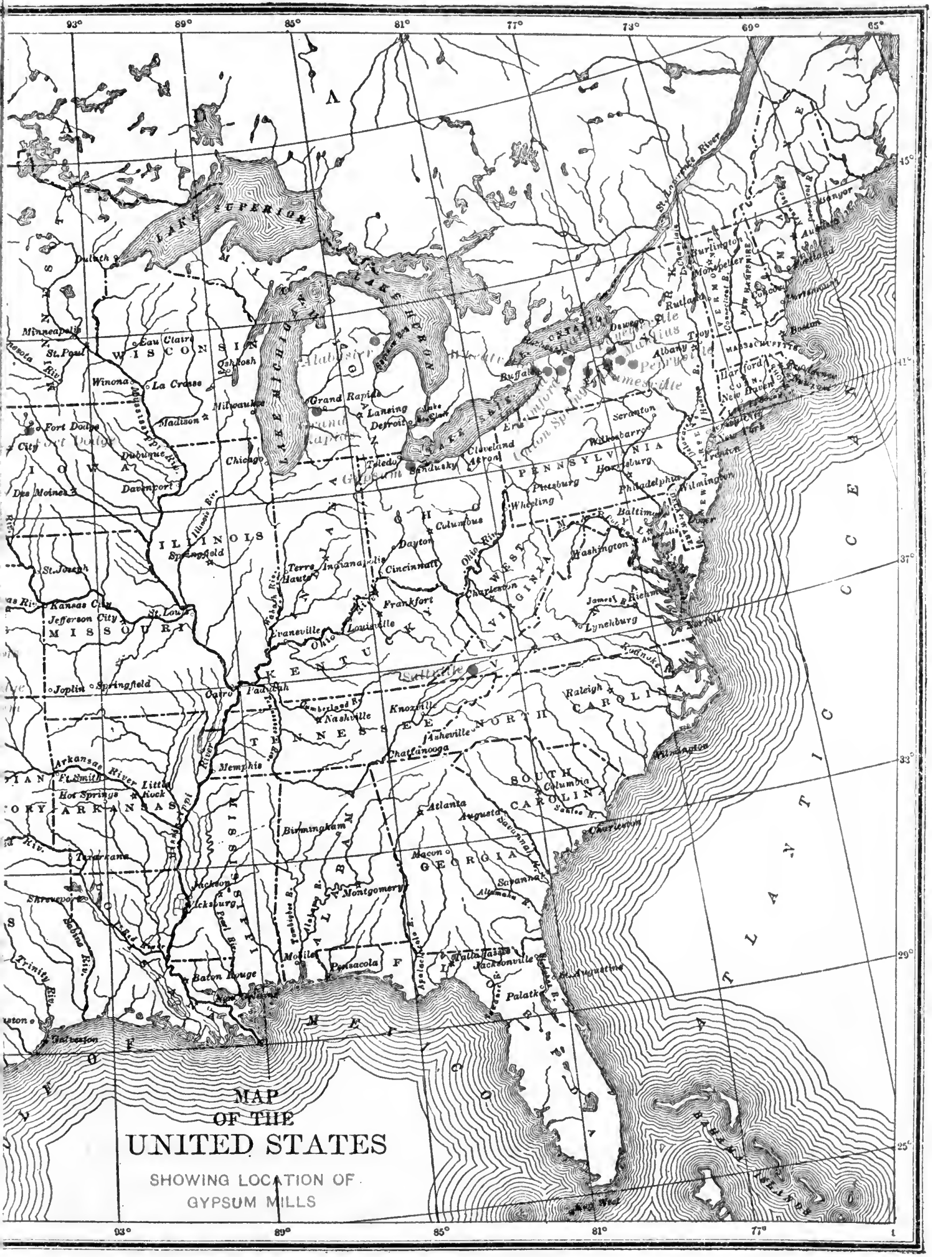

FIG. I.

[*To face p. 14.*

etc. Table 8, on page 53, gives a number of analyses of the gypsum used at various plaster-plants; and a glance at this table will show the kind and amount of impurities which may be expected to occur in commercial gypsum.

Varieties of gypsum.—Owing to differences in form, texture, color, etc., gypsum presents several varieties, some of which have been given distinct names. The ordinary form in which gypsum occurs in the workable deposits is as *massive* or *rock gypsum. Alabaster* is a pure white, fine-grained massive gypsum, occasionally used for statuary, etc. The term *selenite* is applied to the crystalline, white, almost transparent gypsum which occurs frequently, but in relatively small quantity, scattered through a deposit of massive gypsum.

Aside from these various forms of rock gypsum, two less massive forms of the mineral are to be noted as being of commercial importance. In certain Western States and Territories deposits of *earthy gypsum, gypsum earth,* or *gypsite* occur. These deposits contain an impure, earthy, granular form of gypsum. Deposits of *gypsum sands* are also found in the West, being dunes or heaps of fine grains of gypsum.

Physical properties.—Pure gypsum is white and, when in the crystalline form, translucent. The impurities which it commonly contains usually destroy its translucency and affect its color, so that the mineral as mined is an opaque, fine-grained mass, varying from white to reddish, gray, or brown in color.

Gypsum can be distinguished from most other minerals by its extreme softness, for even when in the crystalline form it can be readily scratched by the finger-nail. When treated with acids it does not effervesce. On heating it loses its water of crystallization and, if previously translucent, becomes a chalky, opaque white. Pure crystalline specimens have a specific gravity * of 2.30 to 2.33.

Anhydrite.—The mineral *anhydrite* is closely related to gypsum, as it is an *anhydrous* lime sulphate, with the formula $CaSO_4$. It therefore corresponds in composition to the product obtained by heating gypsum so strongly as to drive off all of its water of combination (see pages 31, 32). Anhydrite occurs, but in relatively small amounts, in almost all gypsum deposits. Pure specimens have a specific gravity * of 2.92 to 2.98.

Occurrence and origin of gypsum deposits.—Rock gypsum occurs in the form of beds, frequently closely associated with beds of rock salt, and almost always interstratified with thin beds of limestone and

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* Clarke, F. W. Constants of Nature, Part I, pp. 81, 82.

thicker beds of red shales. Such gypsum beds may vary greatly in extent as well as in thickness. Beds now worked in different American localities, for example, vary from six to sixty feet in thickness. The gypsum occurring in the beds frequently contains a considerable percentage of impurities, as is shown by the analyses given in Table 8, page 53.

Deposits of rock gypsum have been formed by the gradual evaporation, in lake basins or shallow arms of the sea, of waters carrying lime sulphate in solution. If any natural water be evaporated to a sufficient extent, it will deposit the salts which it contains, the order in which the various salts are deposited depending principally upon their relative proportions in the water and their solubility. A normal water, whether from stream, lake, or ocean, will carry as its three commonest constituents lime carbonate, lime sulphate, and sodium chloride. If such a water be evaporated, therefore, deposits of limestone, gypsum, and common salt would result: and, as above noted, these three minerals are very common associates in gypsum deposits.

Gypsum-earth deposits consist of masses of small crystals or grains of gypsum, intermingled usually with much clayey matter, sand, etc. Such deposits occur in depressions, and are supposed to be formed by the evaporation of spring-waters which have taken up lime sulphate in solution from underlying beds of rock gypsum, only to deposit it again on reaching the surface and being subjected to evaporation.

In certain areas in the West, notably in Arizona and New Mexico, deposits of gypsum sand occur. These deposits are made up of fine grains of gypsum, worn off from outcrops of rock gypsum and carried by the wind to the place of deposition.

Geologic distribution of gypsum deposits.—Gypsum has a very wide geological range, but the *workable* gypsum deposits of the United States occur at only a few geological horizons. The Salina group of the Silurian carries large gypsum deposits which are worked in New York, Ontario, Ohio, and Michigan. The Lower Carboniferous carries workable gypsum deposits in Virginia, Michigan, and Montana. Most of the deposits west of the Mississippi occur in rocks of Permian or somewhat later age. Three geological series, therefore, carry almost all of the workable gypsum of the United States.

Distribution of gypsum in the United States.—The gypsum-producing localities of the United States are indicated on the accompanying map. This map is taken from the publication cited below,* to which the reader

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* "Gypsum Deposits of the United States," by George I. Adams and others. Bulletin No. 223, U. S. Geological Survey. Washington, D. C.

is referred for a much more detailed discussion of the subject, and from which most of the descriptive matter given below has been abstracted.

East of the Mississippi River, the producing localities are confined to central and western New York, southwestern Virginia, northern Ohio, and two widely separated areas in Michigan; while a large unworked deposit occurs in Florida. West of that river, gypsum deposits are both numerous and widely distributed, and plaster-mills are in operation in fourteen of the Western States and Territories.

Brief descriptions of the gypsum resources of the various States are given below, the States being taken up, for convenience of reference, in alphabetical order.

Arizona.—Gypsum can be obtained in quantity at several localities in southern Arizona, the following being particularly noteworthy: (1) In the Santa Rita Mts., Pima County, southeast of Tucson; (2) in the low hills along the course of San Pedro River, Cochise and Pinal counties; (3) in the Sierrita Mts., Pima County, south of Tucson; (4) in the foothills of the Santa Catalina Mts., Pima County, north of Tucson; (5) on the Fort Apache Reservation, Navajo County. Of these localities only the fourth, north of Tucson, has as yet been commercially developed.

California.—In the Tertiary rocks of California gypsum is widely distributed. It is found throughout nearly all the Coast Ranges, particularly south of San Francisco Bay, in the foothills of the Great Valley, and in the valleys of southern California. Deposits are known to occur in the counties of Fresno, Kings, Monterey, Kern, San Luis Obispo, Santa Barbara, Ventura, Los Angeles, San Bernardino, Riverside, and Orange.

Colorado.—The gypsum-producing localities of Colorado occur at intervals from the northern to the southern border of the State, along the eastern foothills of the Rocky Mountains. "Gypsum has been worked extensively near Loveland: beds have also been opened on Bear Creek, near Morrison, and eight miles to the southeast, on Deer Creek. Quarries have been developed near Perry Park and in the Garden of the Gods, near Colorado City, and also in the vicinity of Canyon City." Other deposits, as yet unworked, are known to occur in the central and western parts of the State.

Florida.—An extensive area of gypsum, 6 to 8 feet thick, has been described as occurring about six miles west of Panasoffkee, Fla., on a low-lying area of hummock-land known as Bear Island. The material has not, as yet, been exploited.

Iowa.—The gypsum of Iowa is confined to a single area of 60 to 70 square miles, near Fort Dodge, Webster County. The material occurs in one bed, which varies from 10 to 25 feet in thickness. It has been extensively worked, eight plaster-mills being now in operation in the district.

Kansas.—"The gypsum of Kansas consists of extensive beds of rock gypsum and a number of deposits of secondary gypsum, or gypsite. Some of the rock gypsum is suited to the manufacture of the finer grades of plaster of Paris, and the gypsite is particularly adapted for wall and cement plasters. There is a sufficient quantity of the gypsite now known to permit extensive operations for a number of years. Certain of the deposits, however, have shown signs of exhaustion, and have been abandoned. It is probable that others will be discovered, as there is a demand for further development of the industry. The rock-gypsum beds are so vast in their proportions that only those which are favorably situated with respect to transportation facilities will probably be worked.

"The area in which gypsum is found is an irregular belt extending northeast and southwest across the State, as indicated on the accompanying map of Kansas (Fig. 2). It is naturally divided into three districts, which, from the important centers of manufacture, may be named the northern or Blue Rapids area, in Marshall County; the central or Gypsum City area, in Dickinson and Saline counties; and the southern or Medicine Lodge area, in Barber and Comanche counties. A number of small areas have been developed between these, connecting more or less closely the three main areas. The gypsum is found at Manhattan and north of that city, though not worked. It is worked at Langford, in the southern part of Clay County, and is found near Manchester, in the northern part of Dickinson County. Gypsum is worked near Burns, and has in past years been worked near Peabody and Furley, and large deposits are known near Tampa. Farther south, in Sumner County, a large mill has been operated at Mulvane, and gypsum has been quarried at Geuda Springs. These different localities show an almost continuous belt of gypsum across the State."

Michigan.—Gypsum is at present worked in two distinct areas in Michigan, while a third locality may prove to be of importance in the future. The two producing areas are (1) in the vicinity of Grand Rapids; and (2) at Alabaster, near Saginaw Bay. The third, and as yet unexploited, area is near St. Ignace, on the Upper Peninsula.

Montana.—Gypsum is worked for plaster in Cascade and Carbon counties, and is known to occur at many other localities in the State.

Nevada.—At Moundhouse and Lovelocks, in northwestern Nevada, gypsum deposits have been developed. Large deposits also occur in southern Nevada.

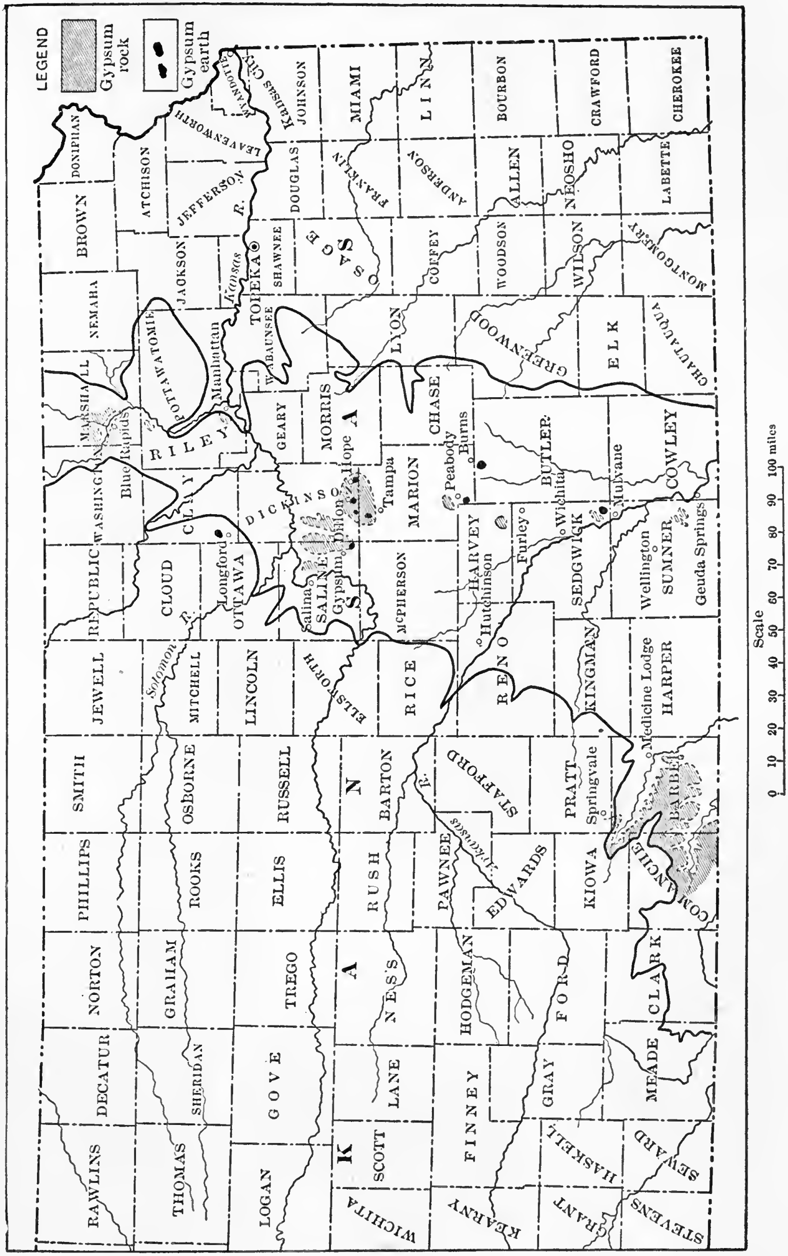

FIG 2.—Map of Kansas, showing location of gypsum deposits.

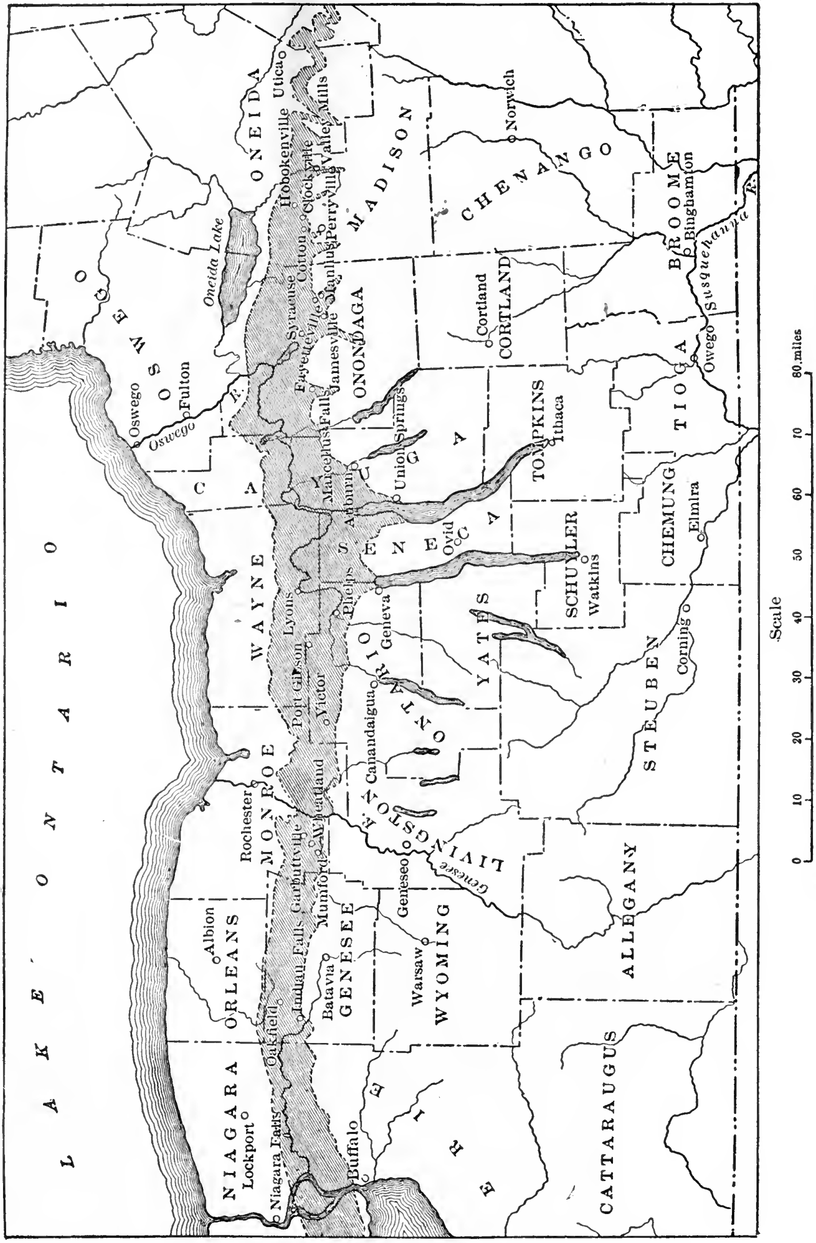

FIG. 3.—Map of New York, showing extent of gypsum-bearing formation.

New Mexico.—Though gypsum is known to occur in quantity at many points, the only commercial development has been at Ancho, where a plaster-mill is now in operation.

New York.—The gypsum in New York State occurs as rock gypsum interbedded with shales and shaly limestones. Several gypsum beds, separated by shales, usually occur in any given section. They are lenticular in shape, but of such horizontal extent that in any given quarry they are usually of practically uniform thickness. Those that are worked vary from 4 to 10 feet in thickness in most of the quarries, but at Fayetteville a 30-foot bed is exposed. The area in which the gypsum-bearing formations are found as shown in the map, Fig. 3, extends through the central part of the State, the productive portion of the belt including parts of Madison, Onondaga, Cayuga, Ontario, Genesee, Monroe, Livingston, and Erie counties.

The most easterly points at which gypsum has been worked are in Madison County, but the product there is small and is marketed locally for use as land-plaster. In Onondaga County, at Marcellus, Fayetteville, and other points, large quarries are operated, part of the product being calcined and part ground for land-plaster. The quarries near Union Springs, in Cayuga County, produce principally land-plaster, as do those of Phillipsport, Gibson, and Victor, in Ontario County. The gypsum from Mumford, Wheatland, Garbuttville, and Oakfield is used chiefly for calcined plaster.

Ohio.—"The gypsum deposits of Ohio which are of economic value consist of beds of rock gypsum occurring in the northwestern part of the State. They have been known since the first settlements were made on the northern shore of Sandusky Bay. The exposures lie at about the level of the waters of the bay, in some places rising a few feet above it. In addition to the deposits of economic importance, gypsum is found in small pockets and isolated bodies throughout the area of the Salina group, which occurs extensively in northwestern Ohio. The deposits which are worked vary considerably in thickness, ranging from a few inches up to 9 feet. On the north shore of Sandusky Bay, in Portage Township, Ottawa County, 1500 to 2000 acres of land have been thoroughly prospected with a core-drill, and it has been shown that there are from 150 to 200 acres of workable gypsum. On the south shore of the bay, about 2½ miles northwest of the town of Castalia, drilling has shown the presence of another area of workable gypsum. but no developments have yet been undertaken. The location of these deposits is shown on the accompanying map, Fig. 4. It is estimated that at the present

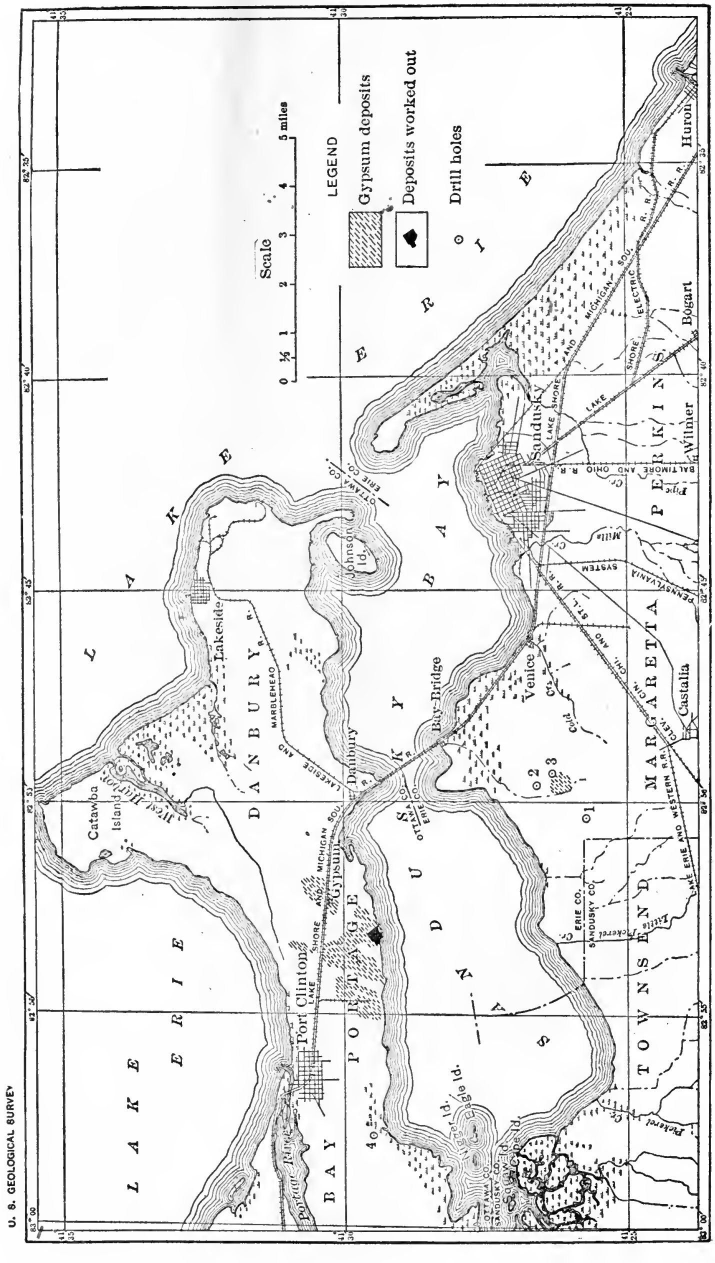

FIG. 4.—Map of the gypsum deposits of Ohio.

rate of production the known deposits will last about twenty-five years."

Oklahoma.—Oklahoma occupies a central position in the belt of country which carries extensive gypsum deposits all the way from the northern part of Kansas into central Texas (see Fig. I). Within its borders the number and thickness of the beds appear to be greater than to the north and south. "The amount of gypsum appears to be inexhaustible. With perhaps two exceptions, each of the western counties contains enough material to supply the United States for an indefinite length of time, and there are in addition considerable deposits in the eastern part of the Territory." The gypsum in Oklahoma may be considered as occurring in four regions: (1) the Kay County region; (2) the main line of gypsum hills, extending from Canadian County northwest through Kingfisher, Blaine, Woods, and Woodward counties to the Kansas line; (3) the second gypsum hills, parallel with the main gypsum hills, and from 50 to 70 miles farther southwest, which extend from the Keechi Hills, in southeastern Caddo County, northwestward through Washita, Custer, Dewey, and Day counties; and (4) the Greer County region, occupying the greater part of western Greer County and the extreme southeastern corner of Roger Mills County.

The deposits in Kay County consist of earthy gypsum, or gypsite. In the other three regions rock gypsum predominates, although there are numerous localities where earthy gypsum occurs in workable bodies.

Oregon.—Gypsum occurs in Oregon in only one known and exploited locality. This is on the eastern border of the State, near the middle point of the boundary-line, on a ridge dividing Burnt River and Snake River. A plaster-plant located at Lime uses material from this locality.

South Dakota.—"In the Black Hills uplift there is brought to the surface an elliptical outcrop of the Red Beds surrounding the high ridges and plateaus of the central portion of the Black Hills. The area is about 100 miles long by 50 miles wide, and the outcrop zone has an average width of 3 miles, except in a few districts where the rocks dip steeply, where it is much narrower. The formation consists mainly of red sandy shales, with included beds of gypsum at various horizons, some of which are continuous for long distances, while others are of local occurrence. The thickness of the deposits varies greatly, but in some districts over 30 feet of pure white gypsum occur, and nearly throughout the outcrop of the formation it contains deposits of sufficient thickness and extent as to have commercial value.

"The gypsum is a prominent feature about Hot Springs. Here the principal beds occur about 60 feet above the base of the formation and have a thickness of 33½ feet, exclusive of the 10-foot parting of shale between them, but this thickness diminishes somewhat northward and rapidly southward."

Texas.—"The largest area in Texas containing deposits of gypsum lies east of the foot of the Staked Plains, in northern Texas. The beds have an approximately northeast-southwest strike and extend from Red River to the Colorado in an irregular line, the sinuosities of which are produced by the valleys of the eastward-flowing streams. This belt is a continuation of the deposits in Oklahoma.

"In the eastern part of El Paso County, to the east of Guadaloupe mountains, there is an area of gypsum which extends beyond the border of the State northward into New Mexico. It lies north of the Texas-Pacific Railroad and west of Pecos River. In a few localities this great plain of gypsum is overlain by beds of later limestone and conglomerate. The gypsum is conspicuously exposed along the course of Delaware Creek, a stream rising in the foothills of the Guadaloupe Mountains and flowing eastward into the Pecos.

"In the Malone Mountains in El Paso County there is a third area which contains notable deposits of rock gypsum. This locality has the advantage of being situated near the Southern Pacific Railway."

Utah.—"The more important known deposits occur in the central and southern portions of the State, in Juab County, east of Nephi; in Sanpete and Sevier counties, near Salina; in Millard County, at White Mountain, near Fillmore, and in Wayne County in South Wash. They are all of the rock-gypsum type, except the one near Fillmore, which is in the secondary form of unconsolidated crystalline and granular gypsum blown up from dry lakes into dunes. Deposits are also known in Emery County, about forty miles southeast of Richfield; in Kane County, near Kanab; in Grand County, between Grand River and the La Sal Mountains; in Sanpete County, near Gunnison; in the eastern part of Washington County (?), between Duck Lake and Rockville, and at other places. Recently enormous deposits of gypsum have been reported from Iron County, at points so far from lines of transportation, however, as to render their exploitation impracticable for the present."

Virginia.—All the workable gypsum deposits of Virginia occur in Washington and Smyth counties, in the valley of the North Fork of Holston River. The area within which the known deposits are located is a narrow belt about sixteen miles in length, extending from a short distance southwest of Saltville to a point about three miles west of Chatham Hill post-office.

The material occurs as rock gypsum, interbedded with shales and shaly limestones of Carboniferous age. The beds of gypsum average 30 feet in thickness at the localities at which they are now worked. The rocks of the district dip at a high angle, however, usually between 25° and 45°, so that certain wells which have been drilled are in the gypsum for long distances, and accordingly immense thicknesses of gypsum have been erroneously reported, because the inclination of the deposits was not taken into account. Near Saltville the dip of the gypsum beds which are worked is toward the northwest; at the mines farther up the valley the dip is to the southeast.

The development of the gypsum industry in this area has been governed almost entirely by the transportation facilities. The deposits in the upper valley, though extensive and easily workable, have not been largely exploited, owing to the long wagon-haul necessary. The deposits at Saltville and Plasterco, which are on a branch of the Norfolk and Western Railroad, have furnished the principal output.

Throughout the entire area the dip of the gypsum beds is so high as to require mining, except at the commencement of the working.

Wyoming.—Though gypsum deposits occur at many localities in the State, only two plaster-plants are at present in operation. These are located at Laramie and Red Buttes respectively. A considerable extension of the Wyoming plaster industry may, however, be expected; for the supplies of gypsum are large and accessible.

Canada.—Gypsum occurs in New Brunswick, associated with Lower Carboniferous limestones, particularly large deposits being shown near Hillsboro, Albert County. An analysis of a typical sample from Hillsboro is given as no. 25, of Table 8, page 53.

The gypsum deposits of Ontario occur in the form of beds, associated with shales and limestones, in the Salina group. The principal exploited deposits are located along the valley of Grand River, from Paris in Brant County to near Cayuga in Haldimand County.

Extensive gypsum beds also occur in Devonian limestones along the Moose and French rivers, near James Bay: but these deposits are as yet entirely undeveloped.

In Nova Scotia thick beds of gypsum occur near St. John Harbor, Port Bevis, and Baddeck Bay, associated with Carboniferous limestones. An analysis of gypsum from near Baddeck Bay is given as no. 26 of Table 8, page 53.

Of the Canadian gypsum deposits, those of New Brunswick and Nova Scotia are of interest to American producers, for they have supplied large quantities of crude gypsum to plaster plants located in the

United States. Most of this Canadian gypsum is used in plants located in the seaboard cities, but a considerable amount of it is calcined as far inland as Syracuse, N. Y.

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Excavation and handling of rock gypsum.—Deposits of rock gypsum are worked either in open quarries or in mines, the choice depending on the thickness of the bed, its dip, and the amount of stripping necessary. Usually work is commenced in an open cut on the outcrop of the gypsum bed. After the entire available face on the property has been opened in this manner, it is necessary to decide whether the workings can be most economically driven as underground tunnels or slopes, or by stripping and open-cut work. At the Severance quarries at Fayetteville, N. Y., over 40 feet of shale and limestone stripping is removed, but the total thickness of gypsum beds shown here is 60 feet; and such heavy stripping could not be justified in order to work thinner beds.

Under ordinary conditions the cost of quarrying gypsum may range from 20 to 35 cents per ton, as compared with 40 to 60 cents per ton for mining it. In mining, large pillars must be left at frequent intervals, and timbering is necessary, in addition, for extensive workings.

Mining methods.—The mining methods practiced at a typical Kansas locality are described * as follows by Crane:

"As a rule, there is little or no system employed in laying out the workings. Main lines of haulage are run as continuations of the surface drifts, other openings being run parallel with them on further development, or run from the foot of a shaft sunk to the workable deposit. On one or both sides of the haulageways rooms are driven, which often run together, thus leaving odd and very irregularly shaped pillars. Long working-faces are often formed, which must be again broken by passages forming pillars for the support of the roof. Usually, however, single rooms, more or less irregular in shape, are opened up and worked until the handling of the product becomes inconvenient, when new and more advantageously placed openings are begun.

"The mine in question was opened by an adit, which, beginning on a fairly steep hillside, at a point on a level with the second floor of the mill, extends into the hill for a distance of about 1000 feet. No special attempt was made to align the adit, consequently considerable useless work was done. For the first 400 feet the adit runs approximately north; the next 300 feet shows a marked variation from the north-and-south line. An attempt was then made to rectify the deviation by driving a right-angled offset 25 feet in length; the remaining 300 feet was driven approximately parallel with the first 400 feet.

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* Crane, W. R. The gypsum-plaster industry of Kansas. Eng. and Mining Journal, p. 442, March 17, 1904.

"Unfortunately, the adit was driven so nearly level as to render drainage very difficult, and much water stands in depressions on the limestone floor.

"The adit is lined with rough-hewn oak, walnut, and red-elm timber, except the last 300 feet, which has round timbers of similar material. Three-quarter sets—that is, sets with posts and caps only—are employed. The posts and caps are 6 feet 2 inches and 6 feet 4 inches long, respectively, both being 8×8 inches in section. They are spaced 36 inches. The posts stand on a limestone stratum 2 feet in thickness, and therefore require no sills. The sets for the first 700 feet are lagged with 2×12-inch oak plank; the remaining 300 feet has plank lagging on the caps and pole-lagging on the posts. A single track of 36-inch gauge is laid in the middle of the tunnel for the mine-cars, which are drawn by mule-power. The cars have a capacity of from 800 to 1000 lbs. gypsum.

"The gypsum mined is 8.5 feet thick and is won by shooting it from the face or sides of the rooms, holes being bored by hand-operated post-augers, Hardscop make. The holes are 1.5 inches in diameter and range from 3 to 6 feet deep. Black powder of C grade is usually employed, the charge ranging from 6 to 14 inches per hole. Squibs are employed in firing the charges. The cost of explosive per ton of gypsum extracted is about four cents.

A 4×6-foot air-shaft connects the end of the adit with the surface, 96 feet above."

Working gypsum-earth deposits.—Deposits of gypsite or gypsum earth, being purely surface deposits of a soft, granular material, can be worked best by methods entirely different from those used in excavating rock gypsum. The gypsum earth is not only soft, but frequently carries a large percentage of moisture: and as it freezes deeply because of this moisture, the Kansas deposits can be worked only during warm weather. If the gypsum earth is covered by soil or sand, this is stripped. The gypsum earth is then loosened by disk harrows or plows, and taken up by wheeled scrapers. It is then taken to drying-sheds, in order to get rid inexpensively of as much of the water as possible. The cost of working a gypsum-earth deposit, under average conditions, may fall between 10 and 25 cents per ton.

CHAPTER II.

CHEMISTRY OF GYPSUM-BURNING. MANUFACTURE OF PLASTERS

BEFORE taking up the actual methods and details of plaster-manufacture, it will be of advantage to discuss briefly the chemical and physical principles on which the industry is based.

Chemistry of gypsum-burning.—Pure crude gypsum is a hydrous sulphate of lime, with a chemical formula $CaSO_4+2H_2O$. This corresponds to the composition:

$$CaSO_4+2H_2O=\left\{\begin{array}{l} \text{Lime sulphate } (CaSO_4)\left\{\begin{array}{ll} \text{Lime } (CaO)\ldots\ldots & 32.6\% \\ \text{Sulphur trioxide } (SO_3)\ldots\ldots\ldots\ldots & 46.5 \end{array}\right\}=79.1\% \\ \text{Water } (H_2O)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots = 20.9 \\ \hline \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad 100.0 \end{array}\right.$$

If pure crude gypsum he heated to a temperature of more than 212° F. and less than 400° F., a certain definite portion of the water of combination will be driven off, and the gypsum thus partially dehydrated will be plaster of Paris. Plaster of Paris has the formula $CaSO_4+\frac{1}{2}H_2O$, corresponding to the composition:

$$CaSO_4+\tfrac{1}{2}H_2O=\left\{\begin{array}{ll} \text{Lime sulphate } (CaSO_4)\ldots\ldots\ldots & 93.8\% \\ \text{Water } (H_2O)\ldots\ldots\ldots\ldots\ldots\ldots & 6.2 \end{array}\right.$$

Three fourths of the original water of combination have therefore been driven off in the course of the process. Dehydration to this extent can, as above noted, be accomplished at any temperature between 212° F. and 400° F. In actual practice, however, it is found most economical of fuel and time to carry on the process at the highest allowable temperatures; and 330° to 395° F. may be regarded as the usual limiting temperatures for plaster-manufacture.

About 400° F. is a critical temperature, for if gypsum be heated at temperatures much above this, it loses *all* of its water of combination, becoming an entirely anhydrous sulphate of lime, and useless as a normal plaster. Under certain conditions, however, gypsum burned at temperatures above 400° F. gains valuable properties. Such highly burned gypsum products will be considered in Chapter IV, under the head of Flooring and Hard-finish Plasters.

Recurring to plasters burned at temperatures lower than 400° F., it may be said that if the gypsum is pure, the resulting plaster will harden or set very rapidly when mixed with water, reabsorbing sufficient water to regain its original composition of $CaSO_4+2H_2O$. Such quick-setting pure plasters are conveniently grouped as plaster of Paris. If, however, the crude gypsum carried a large percentage of impurities, or if certain materials are added to the plaster after burning, the product will set much more slowly. Such slow-setting plasters are of value in structural work, and are marketed under the somewhat misleading name of "cement plasters". The term is unfortunate, because such "cement plasters" are in no way related to the much better known "hydraulic cements" discussed later in this volume.

Using the properties above noted as a basis for classification, the group of plasters may be subdivided as follows:

CLASSIFICATION OF PLASTERS.

A. Produced by the incomplete dehydration of gypsum, the calcination being carried on at a temperature not exceeding 400° F.
    1. Produced by the calcination of a pure gypsum, no foreign materials being added either during or after calcination. . PLASTER OF PARIS.
    2. Produced by the calcination of a gypsum containing certain natural impurities, or by the addition to a calcined pure gypsum of certain materials which serve to retard the set of the product. CEMENT PLASTER.

B. Produced by the complete dehydration of gypsum, the calcination being carried on at temperatures exceeding 400° F.
    3. Produced by the calcination of a pure gypsum. . . FLOORING-PLASTER.
    4. Produced by the calcination, at a red heat or over, of gypsum to which certain substances (usually alum or borax) have been added. . . . . HARD-FINISH PLASTER.

Commercial classification of plasters.—In the trade the names above suggested are used quite extensively, but at times in a careless and indefinite fashion.

Calcined plaster commonly means a burned plaster to which no retarder has been added. If the gypsum from which it was made was pure, the resulting *calcined plaster* will be a *plaster of Paris*, as defined above. If the gypsum used was impure, however, the resulting *calcined plaster* would be a *cement plaster*, as defined above.

Stucco is almost a synonym for *plaster of Paris*, as it contains no retarder and is made from fairly pure gypsum: but the product handled commercially as *plaster of Paris* is usually more finely ground than *stucco* and is as white as possible.

Wall-plasters are made by adding not only retarder but also hair (or some other fiber) to *calcined plaster.*

Keene's "cement", Parian "cement", etc., are plasters used as hard finishes in buildings. Their properties are due to certain peculiarities of their manufacture, for which reference should be made to Chapter IV.

In the present chapter the manufacture of plaster of Paris, cement plaster, and wall-plaster will be taken up, and followed by a chapter on the properties of the resulting products. The manufacture and properties of the flooring and hard-finish plasters will be discussed together in Chapter IV.

Manufacture of Plaster of Paris, "Cement Plaster", and Wall-plaster.

Though plaster of Paris and "cement plasters" are very distinct so far as properties and fields of use are concerned, their processes of manufacture are so similar that they will be treated together in this chapter. It will be recalled that in manufacturing plaster of Paris a pure gypsum is used, so that the product sets very rapidly, while in making cement plasters slowness of set is obtained either by using a naturally impure gypsum or by adding a retarder to the material during or after its manufacture. Aside from this difference, and a slight difference in the calcining temperature, which is usually somewhat lower for plaster of Paris than for cement plaster, the methods employed in making the two products are closely similar.

Two operations are necessary in manufacturing both kinds of plaster: the raw material must be properly calcined and finely ground. The grinding may either precede or follow the burning, for the order of the two operations depends largely upon what calcining process is used. If the burning is carried on in kettles, the grinding is usually done first; but if the burning is carried on in ovens or rotating cylinders, the raw material is necessarily or advisably fed in lumps, and the fine grinding, therefore, follows the burning. In the present chapter the subject will be discussed under the following headings:

(1) Grinding gypsum and plaster.
(2) Calcining by the oven process.
(3) Calcining by the kettle process.
(4) Calcining by the rotary cylinder process.
(5) Addition of retarders and acceleration.
(6) Costs of plaster-manufacture.

Grinding gypsum and plaster.—In American plants using the kettle-calcining process the gypsum is finely pulverized *before* calcination. This pulverizing is usually accomplished in three stages, though when gypsum earth is used instead of rock gypsum the coarse crushers are dispensed with. The three stages are:

(1) The lump gypsum, as quarried, is crushed to 2- to 4-inch size in a Blake, Gates, or other coarse crusher.

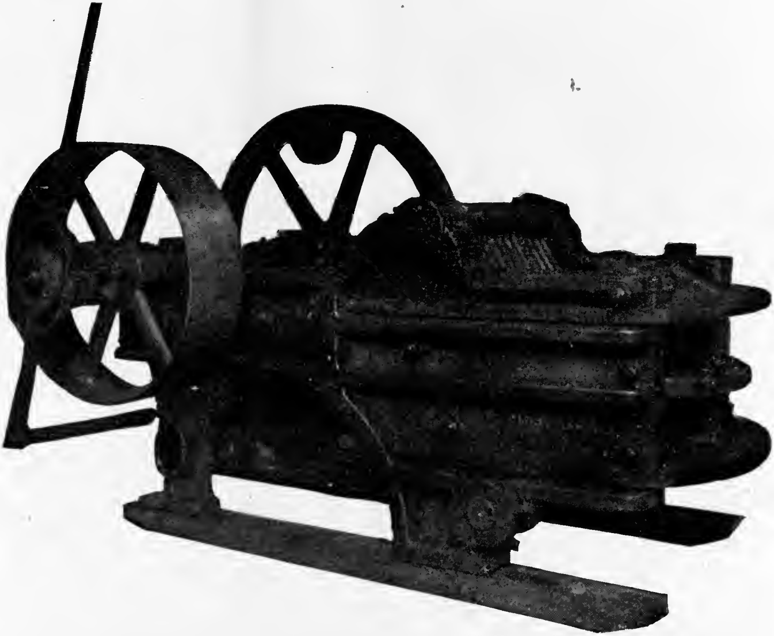

Fig. 5.—Nipper for coarse crushing of gypsum. (Butterworth & Lowe.)

(2) The product of the coarse crushers is fed to reducers of the coffee-mill type, which crush it to about $\frac{1}{4}$ inch or so.

(3) The final pulverizing is accomplished in either buhrstone mills, Sturtevant rock-emery mills, or Stedman disintegrators. These reduce the gypsum so that from 55 to 65 per cent will pass a 100-mesh sieve, and it is then ready to be fed to the kettles.

A typical series of gypsum-grinding machinery is shown in Figs. 5–8. Fig. 5 shows a "nipper", used for the first coarse reduction. It is a heavy crusher of the jaw type, and when used for gypsum-crushing is usually equipped with corrugated jaws, in order to prevent clogging. The machine shown in the illustration has a jaw-opening of $16\frac{1}{2}'' \times 25\frac{3}{4}''$, and a shipping-weight of 10,200 lbs. A smaller nipper, weighing 8100 lbs. and with a 36″×12″ belt pulley, is quoted as having a capacity of 10 to 14 tons per hour, and is listed at $550.

The "nipper" is usually followed by the "cracker" (Fig. 6), which is a heavy machine of the familiar toothed spindle type. A cracker weighing 8000 lbs. has a capacity of 12 to 15 tons per hour, and is listed at $850.

FIG. 6.—Cracker for intermediate reduction. (Butterworth & Lowe.)

For the final reduction the Stedman disintegrator, Sturtevant rock-emery mill, or ordinary buhrstones are generally used. The last two machines are described in a later section of this volume (pp. 239, 240), as they are quite extensively used in grinding natural-cement clinker.

The Stedman disintegrator (Fig. 7) is composed essentially of four concentrically placed cages, formed of steel bars. Of these cages, the first and third revolve in one direction, the second and fourth in the opposite. The material to be crushed is fed into a hopper which discharges it at the center of the cages. The gypsum lumps are struck by the bars of the inner cage, and thrown outward at high velocity. The bars of the second cage, revolving in the opposite direction, strike them with a blow of double force, and this operation is repeated by the bars of the third and fourth cages in succession.

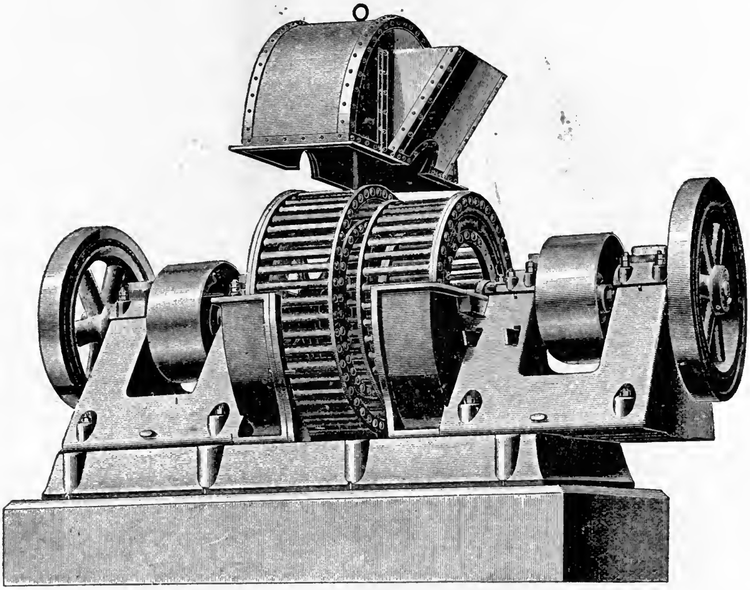

Fig. 7.—Stedman disintegrator, 50-inch, heavy pattern; open and slid apart.

TABLE 5.

SIZES, CAPACITY, ETC., OF STEDMAN DISINTEGRATORS.

Size.	Horse-power.	Capacity in 10 Hours.	Price.	Weight, Lbs.
30-inch disintegrator, heavy pattern. . .	6–9	8 to 10 tons	$300.00	3,000
36- " " " " . . .	12–18	18 " 25 "	450.00	5,500
42- " " light " . . .	12–18	20 " 30 "	500.00	6,000
40- " " heavy " . . .	20–25	25 " 35 "	600.00	10,000
44- " " " " . . .	30–35	40 " 50 "	700.00	12,000
50- " " " " . . .	35–45	60 " 75 "	900.00	15,000

After being reduced as above described, the gypsum is calcined. Usually it is necessary to regrind some of the product which comes from the kettles; and this may be accomplished in any of the fine grinders above noted.

When the rotary process is used, it is customary not to pulverize the material until *after* calcining. As calcined plaster is much easier to grind than crude gypsum, a considerable saving in power and repairs is effected by this difference in practice.

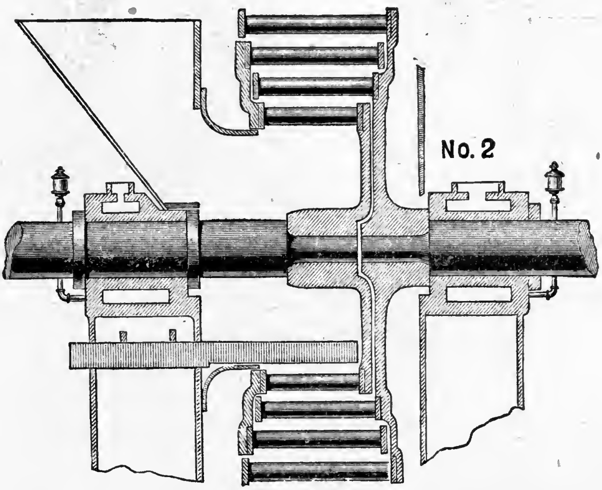

Fig. 8.—Stedman disintegrator, showing cage construction.

Calcining in ovens.—In the manufacture of the higher grades of plaster of Paris it is necessary that the material should be calcined with extreme uniformity and at exactly the proper temperature. This uniformity in burning is attainable in ovens, though the process is necessarily expensive in fuel and labor. For these reasons the oven process has not been used in the United States, though it still persists in Europe for certain grades of plasters.

Calcining in kettles.—The favorite process in the United States, particularly in the plaster-plants of the Middle West, is that in which the calcination is effected in kettles. As noted later in discussing continuous calcining processes (pp. 46–50) the kettle process is slow, low in output, and expensive in fuel. For these reasons it will probably disappear as the continuous rotary calciner becomes perfected; but at present it is still used in the majority of American plaster-plants. The statements above should not be construed as a too sweeping condemnation of the kettle process, for that process is undoubtedly far superior in economy to its European progenitor, the oven process.

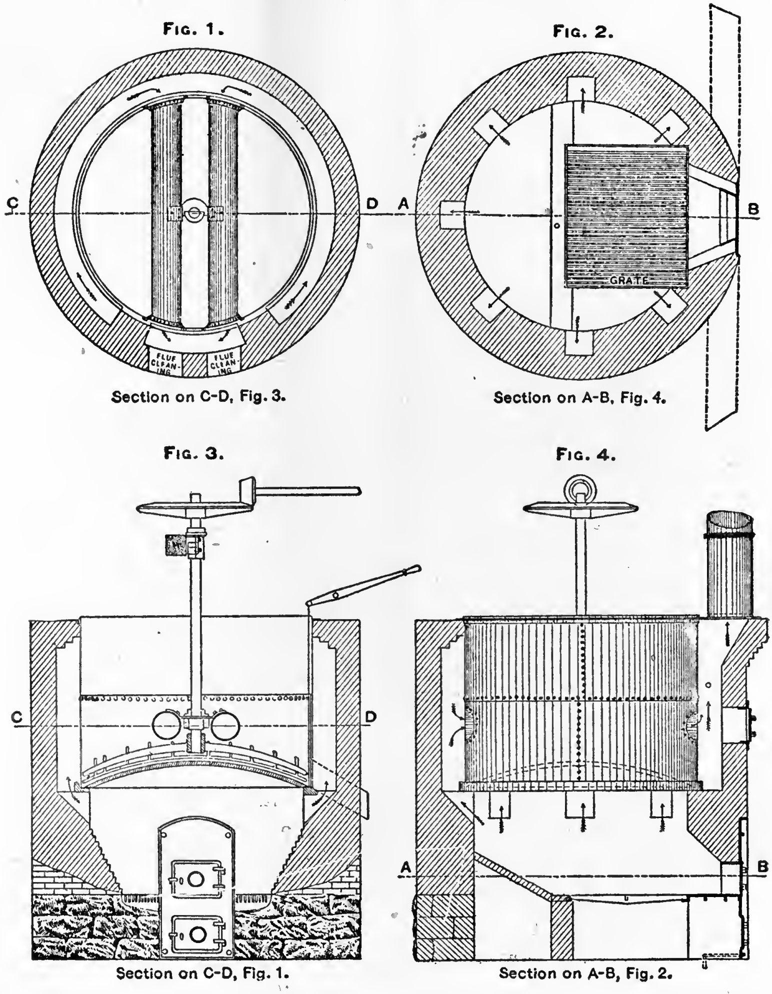

Fig. 9.—Construction and setting of gypsum-kettles. (Trans. Am. Inst. Min. Engrs.)

The following description of the process of calcining plaster in kettles is abstracted, in large part, from an admirable paper * by Wilkinson.

In this process the gypsum is ground, and charged into cylindrical

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* Trans. Am. Inst. Mining Engineers, vol. 27, pp. 514 et seq.

"kettles". Heat is applied both at the bottom of the kettle and by flues passing entirely through the cylinder.

A heavy stone or brick masonry support is built for the kettle, inclosing a fire-space in the form of an inverted cone about 4 feet high. At the top of this cone a cast-iron flanged ring is set in the masonry.

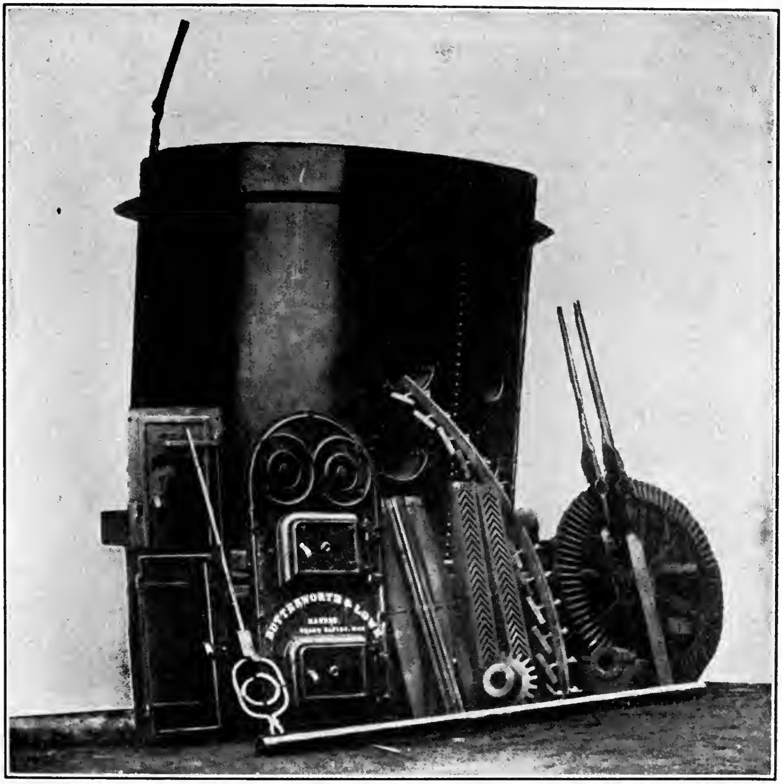

Fig. 10.—Four-flue kettle, with accessories, dismounted. (Butterworth & Lowe.)

On this flange is placed the "kettle-bottom", which is an iron casting, concavo-convex in shape, a little less than 8 or 10 feet in diameter, with the convexity placed upward, the rise being 1 foot. This bottom has a thickness of $\frac{3}{4}$ inch at the edges and 4 inches at the crown. Kettle-bottoms must be made of the best scrap-iron, as ordinary scrap-iron does not last as long as pig. Sheet steel has been tried, but does not serve as well as the best scrap. "The life of a kettle-bottom is terminated by cracking. The cracks can be calked with asbestos cement, but the expense of stoppage and repairing soon overcomes the saving."

Within the past few years sectional kettle-bottoms have been introduced quite extensively. A kettle of this type is shown in Fig. 11, in which the kettle-bottom is composed of a central circular section and six other sections fitting around it. These sections are made of cast iron. The principal merit of this design is that in case any section of the kettle-bottom burns out, it can be replaced without disturbing the kettle or brickwork.

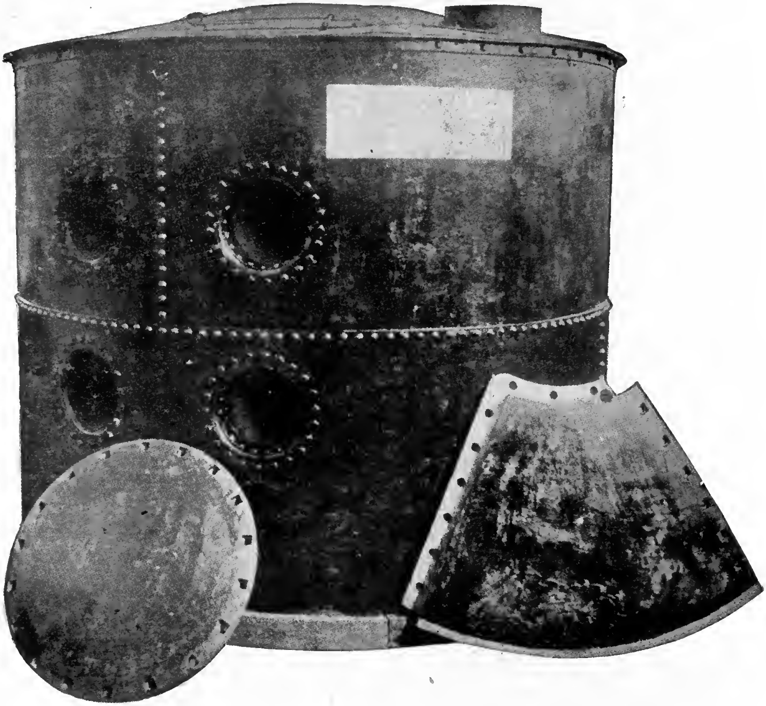

FIG. 11.—Kettle with sectional bottom. (Des Moines Mfg. Co.)

The kettle, which is placed on the kettle-bottom, is of boiler iron ⅜ to ⅝ inch thick, and is commonly 8 to 10 feet in diameter and 6 to 8 feet deep. Such a kettle holds about 7 to 12 tons of raw material, producing from 5½ to 10 tons of plaster. The kettle has two or four flues 12 inches in diameter, placed horizontally about 8 inches above the crown of the kettle-bottom and separated externally about 6 inches. After the kettle has been set, brick masonry is erected around it, gradually converging at the top to meet the top rim of the kettle. The first floor of the mill is usually built around the kettle about a foot from the top, sometimes level with the top, to facilitate shoveling the raw material into the kettle, and the kettle with its supports is in the basement, with storage room for fuel conveniently arranged in front of the kettle. Ports are made through the side of the base ring, and the heat from the furnace is deflected by bridges around the surface of the kettle, so that the heat may cover every part of the kettle, pass through the flues, and finally make exit through a regular stack.

At the top the kettle is covered with a sheet-iron cap having a movable door, through which the raw material is introduced, usually by a chute fed by an elevator.

The shipping-weight of an 8-foot kettle is about 15,000 lbs., and of a 10-foot kettle about 18,500 lbs. Their list prices are about $1200 and $1600, respectively.

The kettles are usually arranged in line and worked in pairs, with one feeding chute and one pit for calcined material for each pair. It is necessary that the material in the kettle be kept constantly agitated, and for this purpose a line shaft carrying a 1-inch vertical pinion-wheel runs over the kettles and a 4-inch vertical shaft with a 5-inch horizontal crown-wheel runs from this to the bottom of each kettle, being supported by a saddle placed between the flues. At the bottom of the vertical shaft a curved cross is attached, to which are affixed movable teeth with paddles, run at 15 revolutions per minute, which are so adjusted as to throw the material from the periphery to the center. From 10 to 25 H.P. are required to run one agitator. Should the agitation stop, or the teeth become broken, the material settles down on the bottom, and, owing to the intense heat, the bottom is almost instantly melted through. The material, which when hot is very fluid, runs through like water and quenches the fire. Stoppage of the agitation can usually be detected by the calciner, who stands above and is supposed to watch the process of calcination constantly.

In burning plaster of Paris the temperature does not exceed 340° F., but when gypsite (gypsum earth) is used a higher temperature is required, averaging close to 396° F., probably owing to the foreign matters included in the gypsite.

In starting a kettle, the heat is gradually applied, and the crude material is gradually fed in and constantly agitated. This process is slow and requires some length of time, owing to the vast amount of mechanically held water which must be evaporated when the wet gypsum earths are used. Material is gradually added until the kettle is full, and as the temperature rises the contents boil violently, much like water, at 220°–230° F. (105°–110° C.). When the mechanically held water is evaporated

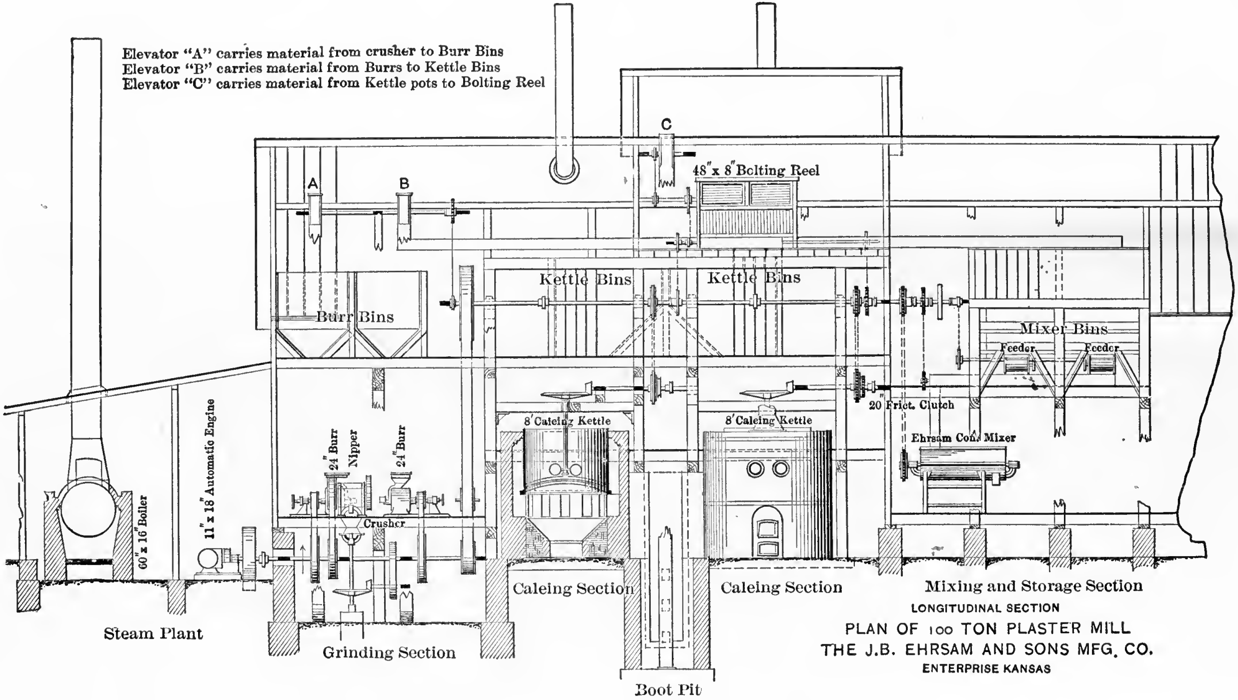

FIG. 12.—Section of 100-ton plaster-mill, kettle process.

the contents of the kettle settle. Further heating, however, brings on boiling again, at about 290° F. (=143° C.), part of the water of combination being now driven off. The point at which the process is complete, 340°–396° F., is known to the expert calciner by the manner in which the material boils and by its general appearance, and at the proper moment the calciner allows the charge to blow out through a small gate at the bottom and in the side of the kettle, controlled by a lever. In plaster-of-Paris plants thermometers are commonly used to govern the temperature exactly, but in gypsite plants, whose raw material is not so uniform in composition, the proper point varies slightly and is usually best known by an experienced calciner.

The escaping steam is let off by means of a stack let into the sheet-iron cover of the kettle parallel with the smoke-stack, and this stack contains near its base a separator similar to the steam-separators, for the purpose of retaining the plaster-dust. It has been found by raising the iron cover about 18 inches and putting on proper sides, that it furnishes a chamber above the boiling material and greatly assists the escape of the steam from it.

From the kettle the hot material runs like water into a fire-proof pit. The kettles are usually run in couples so that one pit will do for two kettles; and one chute will do for two kettles in filling, as the kettles are run at slightly different periods. Each kettle contains a charge of about five tons of manufactured material, and requires from two to three hours to calcine properly. After cooling slightly, the manufactured material is elevated into a revolving screen, which separates all small particles and foreign matter and renders the product uniform. The screenings which usually amount to from ½ to 1 per cent only are sent back to buhrstone and reground. It is usual to have a series of screw-conveyors and elevators both in front of and behind the screen, so as to mix the material thoroughly. Owing to the temperature of the material, all conveyors, elevators, and interior linings must be of metal, and the screen is made of wire cloth. From the screen the material is conveyed to the storage-bins (which are usually arranged to hold 100 or 200 tons), of which there are several, so as to separate, if desired, the runs of different days. The material is usually allowed to fall from a screw at the top of the building, first, that it may spread out and let the different portions mix thoroughly, and, secondly, that it may cool in passing through the air.

Temperature and water determinations made by Slosson and Moudy during an actual run of the Laramie (Wyo.) plaster-plant are given in the following table. The kettle used carried a charge of about five tons, and the run was completed in about three hours. As shown by the water determinations the raw material (gypsum earth) carried a very large percentage of moisture in addition to its necessary water of crystallization. An analysis of the finished product, given below, shows that it is made from a very impure gypsum:

ANALYSIS OF LARAMIE PLASTER.

Lime sulphate ($CaSO_4$)	73.73%
Lime carbonate ($CaCO_3$)	7.86%
Lime (CaO)	2.35%
Magnesium carbonate ($MgCO_3$)	3.04%
Silica (SiO_2)	5.50%
Alumina (Al_2O_3)	0.59%
Water (H_2O)	6.93%

Inspection of this analysis also proves that the plaster still carries a little more water than is theoretically correct. If these various points be borne in mind, the temperature determinations given below will prove of value.

TABLE 6.

TEMPERATURES IN CEMENT-PLASTER MANUFACTURE.

Time.		Temperature.	Pounds Water Contained per 100 Pounds $CaSO_4$.	Percentage Water Contained.	Remarks.
Hrs.	Min.				
0	0	65° F.	59.93 lbs.	32.02%	Kettle charged.
2	0	310° F.	16.85 "	11.69%	Kettle full.
2	20	320° F.	13.66 "	9.69%	Charge boiling.
2	30	340° F.	12.41 "	8.34%	End of first boil.
2	50	390° F.	9.17 "	6.75%	Charge dumped.

Actual equipment of kettle-process plants.—Plans of two kettle-process plants are given in Figs. 12 and 13. The following data, giving the actual equipments of a number of plaster-plants in the United States, will serve to give a good idea of the relation of crushing machinery to number of kettles:

Plant No. 1. (*a*) 2 Butterworth & Lowe nippers.
(*b*) 2 Butterworth & Lowe crackers.
(*c*) 4 runs of 4-foot buhrstones and 1 Sturtevant vertical rock emery mill.
(*d*) 4 10-foot kettles holding 10 tons each.
(*e*) 8 runs of small buhrstones for regrinding finer grades of plaster.

Plant No. 2. (*a*) 1 nipper.
(*b*) 1 cracker.
(*c*) 4 runs of buhrstones.
(*d*) 3 10-foot kettles.

Plant No. 3. (*a*) 1 Godfrey double nipper and cracker.
(*b*) 3 Sturtevant vertical rock emery mills.
(*c*) 3 10-foot kettles.
(*d*) 2 runs of small buhrs for regrinding.

Plant No. 4. (*a*) 1 nipper.
(*b*) 1 cracker.
(*c*) 2 runs of buhrstones and 1 Sturtevant vertical rock emery mill.
(*d*) 2 10-foot kettles.
(*e*) 3 runs of buhrstones for regrinding.

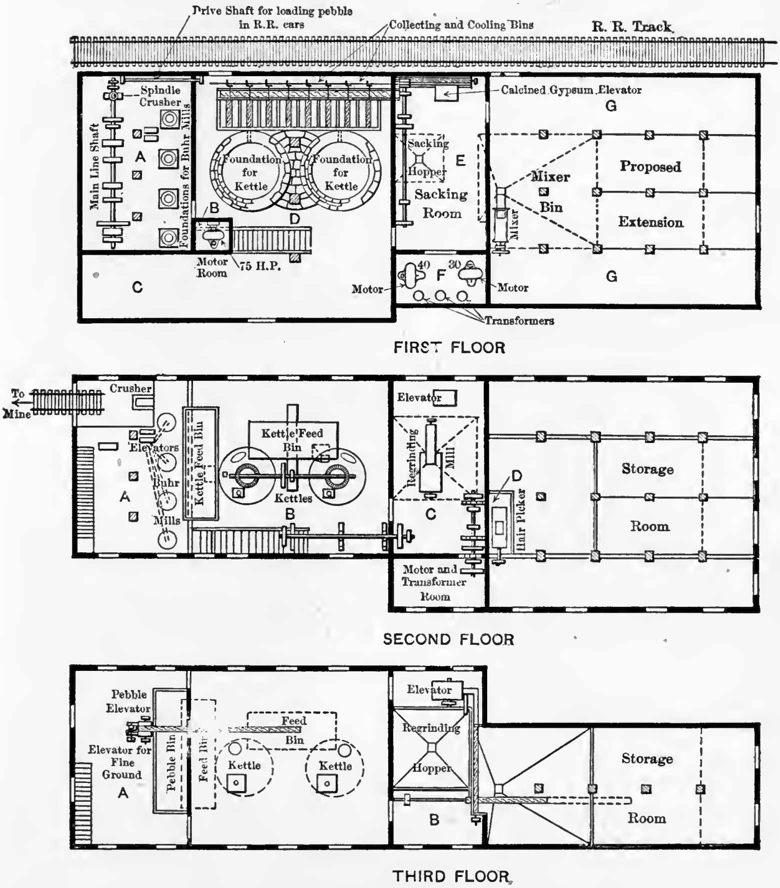

Fig. 13.—Plan of Electric Plaster Co.'s mill, Blue Rapids, Kansas. (Engineering and Mining Journal.)

Plant No. 5. (*a*) 1 nipper.
(*b*) 1 cracker.
(*c*) 2 runs of buhrstones.
(*d*) 1 10-foot kettle.

Plant No. 6. (*a*) 1 nipper.
(*b*) 1 cracker.
(*c*) 4 runs of buhrstones.
(*d*) 2 8-foot and 1 10-foot kettles.
Plant No. 7. (*a*) 1 Stedman disintegrator.
(*b*) 3 runs of buhrstones.
(*c*) 3 10-foot kettles.
(*d*) 2 runs of buhrstones for regrinding.
Plant No. 8. (*a*) 1 Butterworth & Lowe nipper.
(*b*) 1 cracker.
(*c*) 4 runs of buhrstones.
(*d*) 2 8-foot kettles.
(*e*) 1 run of buhrstones for regrinding.
Plant No. 9. (*a*) 1 Blake crusher.
(*b*) 1 cracker.
(*c*) 5 runs of buhrstones.
(*d*) 5 10-foot kettles.
Plant No. 10. (*a*) 1 Blake crusher.
(*b*) 2 runs of buhrstones.
(*c*) 2 10-foot kettles.

Rotary-cylinder processes.—It will probably have been noted by the reader that both of the plaster-calcining processes previously described are discontinuous in operation and consequently expensive in both time and fuel. These defects of the oven and kettle processes are avoided in the rotary cylinder processes now coming into use in both America and Europe. In the United States a rotary process has been adopted in a number of New York plaster-plants, and has been in practical operation for a sufficiently long time to demonstrate its superiority over the kettle process. In Europe, to judge from a recent description of the German plaster industry, rotary plaster calciners have been used for a number of years and have proven entirely satisfactory.

Cummer system.—Most of the American plants using the rotary calcination process have been equipped on the system devised by the F. D. Cummer & Son Co., of Cleveland, Ohio.

The plan of a New York plant using this process is shown in Fig. 14. This plant uses rock gypsum, and with the equipment shown produces 50 tons of calcined plaster per day of eleven hours, six men being required to operate the mill. The rock coming direct from the mine is delivered into the jaw crusher A, where it is reduced so as to pass a $2\frac{1}{2}$-inch ring. Elevator B carries the crushed rock from crusher to screen C, which separates all material that will pass a 1-inch ring. The tailings from the screen pass through the rolls D and meet with the material which passes through the screen. All of the material now crushed to pass a 1-inch ring is carried by elevator *E* and delivered into bin *F*. From this bin the crushed rock is fed mechanically by feeder *H* into the Cummer rotary calciner *G*. In this machine most of the free moisture is eliminated, and the process of calcining also carried forward toward completion. The material delivered from the rotary calciner is steaming and heated to from 350° to 400° F., the exact temperature depending upon the nature and density of the rock. Elevator *J* carries the product from the calciner to the Cummer calcining-bins *K*, where it is allowed to remain about thirty-six hours. During this time the resident heat in the material completes the process of calcination, and the material is cooled, ready for the mills. The now calcined material is mechanically discharged from the bins into elevator *M*, which carries it into the small bins situated over the mills *O*. From the mills the conveyor *R* delivers the pulverized material into screen *S*. The finished material is sacked at *T*. The tailings from the screen are spouted into elevator *M* and returned to the mills.

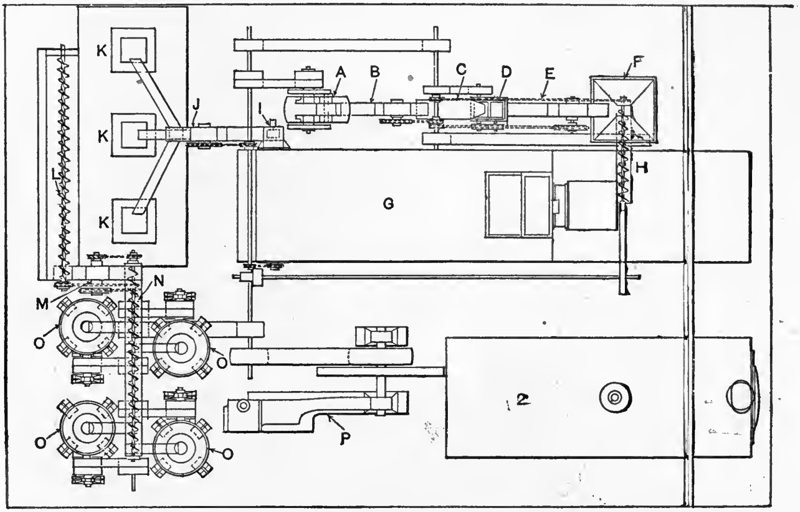

Fig. 14.—Plan of plaster-mill equipped on Cummer rotary calcining system.

The calcining-bins noted above are an integral part of the Cummer process. These bins are built preferably of brick and are lined with paving brick, so that they will not absorb the moisture given off from the gypsum rock during calcination. Three bins are required for each plant, and the capacity of each bin is equal to the daily output of the plant. By the use of three bins a continuous process is obtained. One bin is being discharged of its cooled calcined material while the process of calcination is being completed on the material in the second bin, and the third bin is being filled with material from the rotary calciner. These bins are so constructed that the material in process of calcination is thoroughly ventilated, which allows the heat carried by the material from the rotary calciner to rapidly disseminate itself through the mass and complete the calcining process. While the resident heat in the material is acting upon it, practically no circulation of air through the material is allowed, but as soon as the process of calcining is completed, air at atmospheric temperatures is freely circulated through the mass and the calcined gypsum is rapidly cooled. Each bin is equipped with a simple device which mechanically discharges the material regularly and at any speed desired.

A dust-chamber located above the rotary calciner catches the most finely ground plaster, which is marketed for dental plaster and other special purposes.

The Cummer rotary calciner is shown in section in Fig. 15. Its operation is as follows:

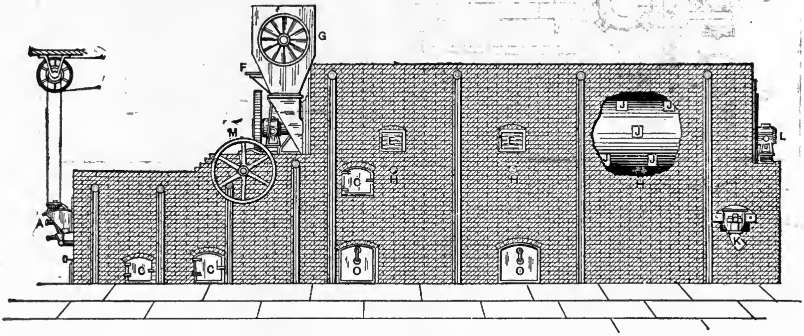

Fig. 15.—Cummer rotary plaster-calciner.

The gypsum rock is fed through a hopper, *F*, into a cylinder set on a slight incline rotating on trunnioned bearings within a brick chamber. The material passes slowly down the cylinder (owing to its inclination and rotation), being thrown about by lifting-blades attached to the inside of the cylinder. It is discharged at *K*, having been subjected during its passage to the heated fuel gases, whose admission and handling will next be described.

The hot gases from the furnace are drawn by the fan *G* into the brick chamber surrounding the cylinder. Cold air is introduced through the registers *E* and *O* and mixed with the furnace gases in such proportions as to give the desired temperature. These gases are drawn into the cylinder through the hooded openings *J* and pass through it in a direction opposite to that taken by the wet material. Pyrometers for control of the temperature may be placed in the holes H in the masonry.

Mannheim system.—A German plaster-plant using a rotary calcining system has recently been described * in considerable detail, and seems worthy of attention as presenting certain interesting differences to the system discussed above. The mill in question is that of the Rhenish Gypsum Company, located at Mannheim, in Rhenish Prussia.

The crude gypsum is passed through crushers and nippers, but is not finely powdered previous to calcining. "When the material comes from the crushers and nippers it varies in size from the finest powder to fragments as large as an ordinary hickory-nut. Varying thus in size, the material goes directly to the calciner."

"The calciner consists of a fire-box with an automatic stoker, which is placed in front of and connected with a chamber containing a rotating cylinder. Above this cylinder is a chamber called the 'forewarmer', through which a spiral conveyor passes from end to end. A pipe leads from the rotating cylinder to the forewarmer and connects at the other end with the chimney. Connected with the fire-box is a fan by which a forced draft is secured. The fire-box is heated to a high temperature, and the fuel gases, forced by the fan, pass through the rotating cylinder and then through the forewarmer. The crude gypsum is carried by bucket elevators from the crushers to a bin above the calciner and thence it flows by gravity into the forewarmer, through which it is carried by the spiral conveyor. It then falls directly into the rotating calciner below. Shelves or buckets on the inside of this cylinder pick up the material and elevate it as the cylinder rotates. When the material nears the top the slant of the shelves is so great that it falls again to the bottom. The strong draft of hot air passing through the cylinder from the fire-box strikes the gypsum as it falls and moves the fragments toward the rear with a velocity directly † proportional to their size. The coarser material moves much more deliberately and thus is exposed to the heat longer than the finer and more readily calcined particles. In this way, though the material entering the rotating cylinder varies greatly in fineness, the coarser material is sufficiently calcined and the finer is not overburned. All of the heat has not been exhausted in passing through the rotary cylinder and this is for the most part saved by forcing the air, after it leaves the cylinder, through the forewarmer. In this process the heat is so completely utilized that the air and furnace gases pass to the chimney with a temperature of only

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* Wilder, F. A. Vol. 12, Iowa Geological Survey, pp. 213–216.

† Evident misprint for "inversely". E. C. E.

80° C. Between the forewarmer and the chimney the dust-chamber is located. Here all of the finer particles are allowed to settle and the air passes on to the chimney practically free from dust. To calcine one ton of gypsum by this method experience has demonstrated that on the average only 100 lbs. of rather inferior bituminous coal are required. An automatic recorder indicates constantly the heat of the rotary cylinder, and this, with the mechanical stoker, insures an even temperature during the entire process of calcining. From the rotary cylinder the gypsum is again elevated to the floor above and passes through a spiral conveyor which is surrounded by a water-jacket. Here the plaster is cooled and passes on to the sieves. That portion of the plaster which does not need further grinding is separated by the sieves and the rest goes to the vertical mills."

The process shows economy in fuel, labor, and power over the older methods. On the other hand, "a limited amount of soot settles in the plaster, and it is slightly coated with calcium sulphide, due to the reaction on the gypsum of the sulphur present in the coal. For ordinary building purposes, however, these do not injure the plaster."

Addition of retarders and accelerators.—It is now the common practice for plaster manufacturers to add retarders to their product, in order to prevent its setting too rapidly for the convenience of the workman. The general discussion of the character and effects of retarders and accelerators can best be taken up in the following chapter. At present it is only necessary to state that the retarder is best added after the plaster is entirely cool, as otherwise most retarders will melt and form lumps in the plaster. From 2 to 15 lbs. of retarder are usually added to the ton of plaster, and the mixing is generally accomplished in a Broughton mixer or some similar device.

The following data relative to the Broughton mixer, which is shown in Fig. 16, are taken from the catalogue of the Des Moines Manufacturing and Supply Company, and will serve to give some idea of the capacity, cost, etc., of the machine.

TABLE 7.

SIZES, CAPACITY, ETC., OF BROUGHTON MIXERS.

Style	A–1	A	B–1	B–2	B–3
Capacity of hopper, lbs.	1800–2000	1000–1400	600	500	250
Bag-holders, number	6	5			
Product per day, 10 hours, tons	60–90	35–50	35	15	7½
Size of pulleys, inches	30×12	24×8	24×8	20×6	16×4
Revolutions per minute	150	150	175	160	160
Horse-power required	18–22	8–12	8–12	5–7	3–4
Shipping weight, lbs.	7300	4750	3800	2300	
List price	$675	$450	$400	$300	$250

Wall-plaster.—An ordinary wall-plaster contains, in addition to whatever retarder may be necessary, a certain percentage of finely picked hair or other fiber. In order to insure thorough mixing with the plaster the hair is first picked to pieces in a hair-picker, which is usually a device of the toothed-drum type revolving at high speed. The hair is then added to the plaster in the proportions of 1½ to 3 lbs. hair per ton of plaster and the materials are fed to the mixer.

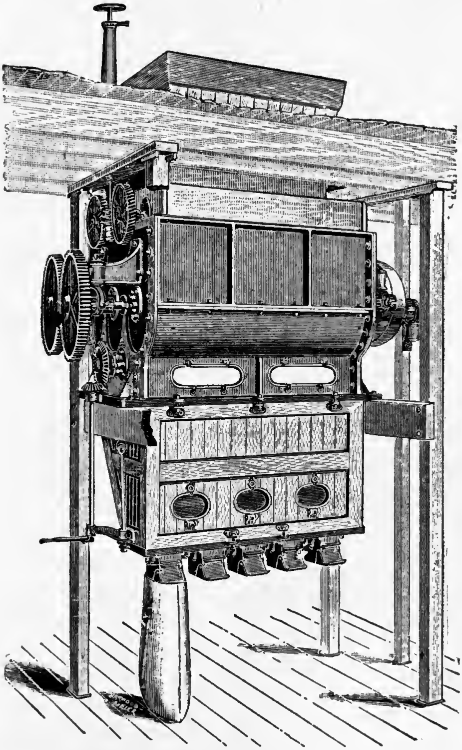

Fig. 16.—Broughton mixer.
(Des Moines Mfg. Co.)

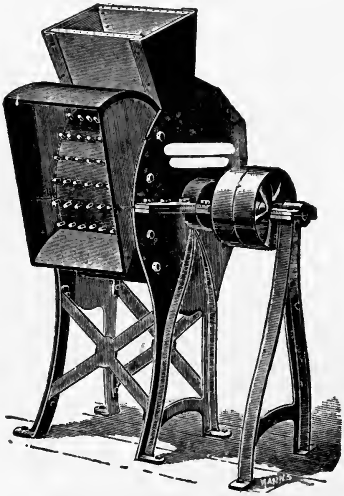

Fig. 17.—Hair-picker.

The hair-picker shown in Fig. 17 is run at a speed of 600 revolutions per minute and will disintegrate 5 to 6 bales of hair per hour. It is listed at $75.

Wood fiber is often used as a substitute for hair, the cottonwood giving a particularly serviceable fiber for this use. The log is barked by hand or machine and cut into sections 20 inches or so in length. These are then placed in a fiber machine, which will usually take pieces 6 to 15 inches in diameter. The fiber is torn off by revolving toothed cylinders between which the log is pressed. One machine will cut enough fiber in nine or ten hours to make 30 to 40 tons of plaster. The usual mix consists of 75 to 150 lbs. wood fiber to one ton of calcined plaster.

Plasters are usually packed in jute sacks containing 100 lbs. or in paper bags containing 80 lbs. An extra charge of 10 cents is commonly made for each jute sack, rebated on the return of the sack. As the sacks may cost the mill 4 to 6 cents each, any sacks not returned furnish a fair profit. A charge of 50 cents per ton of plaster is usually made for packing in paper bags, which are not returnable.

Costs of plaster-manufacture.—An estimate of the cost of plaster-manufacture at Kansas mills, made in 1897 by G. P. Grimsley,* follows.

COST OF PLASTER-MANUFACTURE PER TON.

Mining costs	$0.80
Fuel at mill	0.30
Labor at mill	0.50
Office force and sales agents	1.25
Total cost of plaster per ton	$2.85

Setting aside the question of cost of "office force and sales agents", which varies greatly in different mills, the estimate given above appears to the writer to be very high for mining costs, rather below the average for fuel costs, and about the maximum for labor. The following estimates of cost of manufacture by the kettle process have, therefore, been prepared as giving, in the writer's opinion, fairly close limiting values:

	Max.	Min.	Average.
Mining or quarrying 2400 lbs. gypsum	$0.72	$0.12	$0.30
Power fuel at mill, 75 to 125 lbs. coal	0.19	0.05	0.10
Kiln fuel at mill, 225 to 325 lbs. coal	0.49	0.15	0.30
Labor at mill	0.50	0.30	0.40
Total cost per ton plaster at mill	$1.90	$0.62	$1.10

The rotary process of plaster calcination has not been used at enough plants to give accurate limiting figures of costs, but the following estimates are believed to be fairly close:

	Max.	Min.
Mining or quarrying 2400 lbs. gypsum	$0.72	$0.12
Power fuel at mill, 50 to 80 lbs. coal	0.12	0.04
Kiln fuel at mill, 150 to 200 lbs. coal	0.31	0.10
Labor at mill	0.30	0.18
Total	$1.45	$0.44

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* Mineral Industry, vol. 7, p. 392.

Analyses of gypsum used in actual practice.—The following analyses of both rock gypsum and gypsite (gypsum earth), taken from various sources, will be fairly representative of the materials used for plaster at different plants. For comparison it is well to recollect that a theoretically pure gypsum would consist of lime sulphate 79.10 per cent, water 20.90 per cent, and would contain no silica, alumina, iron oxide, lime carbonate, or magnesium carbonate.

TABLE 8.

ANALYSES OF ROCK GYPSUM USED FOR PLASTER.

+	Silica (SiO_2).	Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3).	Lime Carbonate ($CaCO_3$).	Magnesium Carbonate ($MgCO_3$).	Lime Sulphate ($CaSO_4$).	Water (H_2O).
1	....	....	....	....	79.40	20.30
2	0.35	0.12	0.10	0.25	78.73	20.52
3	0.65	0.17	1.53	0.39	79.30	18.84
4	0.40	0.19	0.25	0.35	78.10	20.36
5	0.35	0.12	0.56	0.57	78.40	19.96
6	1.18	0.15	0.36	0.52	78.04	20.00
7	0.52	0.26	1.87	2.06	75.84	19.47
8	0.34	0.16	1.68	1.30	76.98	19.63
9	0.41	0.29	0.55	0.61	78.25	19.70
10	0.55	0.23	0.86	0.47	78.11	19.54
11	0.38	0.16	....	0.96	77.81	20.37
12	0.19	0.10	1.43	0.34	77.46	20.46
13	0.05	0.08	....	0.11	78.51	20.96
14	n. d.	n. d.	n. d.	n. d.	77.11	19.00
15	tr.	0.54	n. d.	n. d.	76.26	20.84
16	1.24	0.50	2.38	....	77.19	19.03
17	0.56	tr.	1.86	....	77.77	20.28
18	0.68	0.16	n. d.	n. d.	78.08	20.14
19	0.46	0.29	n. d.	n. d.	78.96	20.00
20	0.91	0.60	n. d	n. d.	78.73	19.70
21	0.10	0.70	....	....	79.26	19.40
22	0.02	0.55	....	....	80.14	19.07
23	0.49	0.46	....	....	77.94	20.85
24	1.68	1.95	....	....	72.06	21.30
25	0.10	0.10	....	....	78.55	20.94
26	0.11	....	1.07	....	98.42	20.43

1. Gypsum Station, Calif.
2. Blue Rapids, Kansas } used at Great Western Plaster-mill.
3. " " "
4. " " "
5. Dillon, Kansas.
6. " "
7. Hope, Kansas.
8. " "
9. " "
10. Solomon, Kansas.
11. " "
12. Medicine Lodge, Kansas.
13. Alabaster, Michigan, used at Western Plaster Works.
14. Grand Rapids, Mich
15. " " "
16. " " "
17. Alabaster, Mich.
18 Near Sandusky, Ohio.
19 " " "
20. " " "
21–24. Saltville, Virginia.
25. Hillsboro, New Brunswick.
26. Baddeck Bay, Nova Scotia

TABLE 9.

ANALYSES * OF GYPSITE (GYPSUM EARTH) USED FOR PLASTER.

	Silica (SiO_2).	Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3).	Lime Carbonate ($CaCO_3$).	Magnesium Carbonate ($MgCO_3$).	Lime Sulphate ($CaSO_4$).	Water (H_2O).
1	10.67	0.60	10.21	1.10	59.46	16.59
2	2.17	0.24	2.66	0.95	75.11	19.40
3	2.31	0.37	11.71	0.52	67.91	17.72
4	4.54	0.54	5.07	0.59	71.57	17.82
5	13.50	1.05	7.50	0.76	60.27	17.05
6	7.65	0.52	8.11	0.63	64.72	18.39
7	3.62	0.45	4.09	0.34	71.94	19.87
8	15.08	0.44	7.02		60.51	17.46
9	10.23	1.12	11.77	0.94	58.75	17.10
10	34.35	4.11	8.14	10.52	34.38	8.50
11	9.73	0.78	4.32	tr.	68.29	16.88
12	3.06	0.34	11.03	0.90	67.32	17.24
13	4.25	0.53	3.56	0.21	69.51	20.82
14	4.82	0.79	4.52	0.34	68.14	20.41
15	15.76	0.49	5.14		59.93	18.64
16	8.78	1.98	7.25	1.12	58.25	20.66
17	7.68	0.89	7.39	1.76	63.37	17.77
18	11.78	1.87	7.37	1.00	53.56	18.25
19	6.33	0.53	13.68	0.88	55.71	19.23
20	5.14	0.67	7.36	1.12	66.64	19.95
21	12.13	0.99	3.57	0.88	64.63	16.75
22	17.10	2.04	7.71	1.24	56.58	15.16
23	3.18	0.95	6.18	0.33	69.70	19.44
24	6.49	1.04	6.96	0.27	65.97	18.56
25	17.95	1.43	n. d.	n. d.	61.00	18.44

* The analyses in this table are mostly by Bailey and his associates and are quoted from vol. 5, Kansas Geol. Survey.

1. Marlow, Indian Territory, used for "Royal" brand plaster.
2. Mulvane, Kansas.
3. Burns, Kansas.
4. Tinkler, Kansas, used at Gypsum City.
5. Gypsum City, Kansas, surface of bed, used for "Acme" brand plaster.
6. Gypsum City, Kansas, center of bed, used for "Acme" brand plaster.
7. Gypsum City, Kansas, average, used for "Acme" brand plaster.
8. Gypsum City, Kansas, quick-setting gypsite, used for "Acme" brand plaster.
9. Longford, Kansas, used by Salina Cement Plaster Co.
10. Salina, Kansas.
11. " "
12. Rhoades, Kansas.
13. " " , 4 feet from surface.
14. Rhoades, Kansas, 8 feet from surface.
15. " " , bottom of bed.
16. " " , average of 1 acre.
17. " " , average of 8 samples 2½–3½ feet depth.
18. Rhoades, Kansas, small deposit.
19. " " , material very slow setting.
20. Rhoades, Kansas, average as used in plaster-plant.
21. Dillon, Kansas, used by Salina Cement Plaster Co.
22. Dillon, Kansas, used by Dillon Cement Plaster Co.
23. Dillon, Kansas, used by Dillon Cement Plaster Co.
24. Dillon, Kansas, used for "Agatite" plaster.
25. Okarche, Oklahoma.

Inspection of the analyses quoted in Tables 8 and 9 will show that the rock gypsum used at plaster plants is usually very pure. Until very recently no attempt has been made to utilize the impure gypsum rock which forms such a large proportion of the New York deposits, though there is no technologic reason for not using it. The analyses of gypsite or gypsum earth, on the other hand, are mostly representative of very impure materials, carrying large percentages of sand, clay, and fragments of limestone. The presence of these impurities in the natural raw material is a matter of technologic importance, for the calcined plaster made from such impure materials is naturally very slow setting.

References on plaster-manufacture.—The following papers deal largely with the manufacturing side of the gypsum industry.

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CHAPTER III.

COMPOSITION, PROPERTIES, AND TESTS OF PLASTERS.

In the present chapter the chemical composition and physical properties of plaster of Paris and cement plasters will be taken up in the order named.

Chemical Composition.

Theoretical composition.—A theoretically pure plaster of Paris, being a definite chemical compound ($CaSO_4 + \frac{1}{2}H_2O$), would have the composition: lime sulphate, 93.8 per cent; water, 6.2 per cent. This composition is approached quite closely in plasters made from a pure rock gypsum.

Cement plasters, as has been described on earlier pages, can be made in two different ways, which give two different products so far as composition is concerned. (1) Cement plasters may be made by adding retarders to a pure plaster of Paris. As the retarder is organic matter and rarely amounts to over 1 per cent of the total mass the resulting product will on analysis differ very little from the plaster of Paris of which it was made. (2) Cement plaster may also be made by burning an impure gypsum, with or without the addition of retarder. In this case analysis would show the presence of a large percentage of clayey matter, etc., and a cement plaster of this type will therefore have a composition very different from that of a pure plaster of Paris. Examples of both these types will be found in Table 11, opposite.

Actual composition of plaster of Paris.—The composition of the pure quick-setting plasters here grouped as plaster of Paris, as these plasters appear in commerce, is shown by the following table (10) of representative analyses.

Actual composition of cement plasters.—As noted earlier, a cement plaster when ready for sale differs from the gypsum of which it was made only in the loss of water and the addition of a very small proportion ($\frac{1}{10}\%$ to 1%) of retarder. The difference between the analyses of any two samples or brands of cement plaster will therefore depend on the difference in composition between the gypsums from which the two samples were made.

TABLE 10.

ANALYSES OF PLASTER OF PARIS.

	1.	2.	3.
Silica (SiO_2)	0.00	0.57	0.61
Alumina (Al_2O_3)	0.00		
Iron oxide (Fe_2O_3)	0.00		
Lime carbonate ($CaCO_3$)	0.00		
Lime sulphate ($CaSO_4$)	93.8	94.53	96.44
Water (H_2O)	6.2	4.12	3.51

1. Theoretical composition of pure plaster of Paris.
2, 3. Stucco, made by Ruby Stucco Plaster Co., Ferguson, Oklahoma. 2d Rep. Okla. Dep. Geology, p. 128.

TABLE 11.

ANALYSES OF CEMENT PLASTERS.

	Silica (SiO_2).	Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3).	Lime Carbonate ($CaCO_3$).	Magnesium Carbonate ($MgCO_3$).	Lime Sulphate ($CaSO_4$).	Water (H_2O).
1	39.55	0.61	5.79	0.54	46.99	6.42
2	1.00	0.33	1.50	0.75	88.50	8.00
3	1.20	0.20	1.68	1.18	89.42	6.86
4	4.27	0.47	3.07	1.47	83.55	6.67
5	12.04	1.50	8.44	2.24	71.74	4.80
6	0.97	0.30	0.04	1.28	89.98	7.29
7	0.85	0.16	0.94	1.28	91.07	6.33
8	11.97	0.67	8.11	0.73	71.43	6.98
9	14.67	1.05	10.07	0.95	66.91	6.41
10	5.52	0.40	12.00	1.74	74.43	6.99
11	9.73	0.62	11.30	0.65	72.42	5.49
12	19.43	0.53	9.59		64.42	6.21
13	13.29	0.71	4.77	1.91	73.67	5.78
14	23.38	2.42	n. d.	n. d.	69.41	5.66
15	7.43	0.12	5.07	tr.	78.66	8.49

1. Florence, Colorado.
2. Rhoades, Kansas.
3. Blue Rapids, Kansas, "Crystal Rock" brand, Great Western Plaster Co.
4. Springdale, Kansas, "Roman" brand.
5. " " "Acme" "
6. Blue Rapids, Kansas, "Sunshine" finishing plaster, Great Western Plaster Co.
7. Blue Rapids, Kansas, "Ivory" finishing plaster, Blue Valley Plaster Co.
8–12. Blue Rapids, Kansas, "Acme" cement plasters.
13. Okarche, Oklahoma.
14. " "
15. Quanak, Texas.

Weight and Fineness of Plasters.

Weight and specific gravity. — Pure gypsum, before calcination has a specific gravity of 2.30 to 2.33, corresponding to a weight of about 143½ lbs. per cubic foot, while the specific gravity of plaster of Paris is about 2.57. The apparent specific gravity of cement plaster in bulk is 1.81.* This would correspond to a weight of about 113 lbs. per cubic foot if, no allowance were made for air-spaces. According to the results † of

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* Wilder, F. A. Vol. 12, Iowa Geological Survey, p. 139.

† Tenth Ann. Rep. Wyoming Agric. and Mech. College.

Slosson and Moudy on Laramie plaster, a bushel weighed 64 lbs., and a block composed of 50 parts sand and 100 parts plaster, after being set and dried, gave a specific gravity of 1.5, corresponding to a weight of 93½ lbs. per cubic foot.

Fineness of calcined plasters.—A number of cement plasters, wall-plasters, and allied products from Iowa, Kansas, Texas, and Oklahoma were tested for fineness by Prof. Marston in 1900. The results* of these tests are given in the following table. The tests were made on material purchased in the open market.

TABLE 12.

FINENESS OF CALCINED PLASTERS.

Per cent passing sieve.

Meshes per linear inch	74	100	200
Average diameter of largest particle passing	.00901″	.00452″	.00271″
Gypsum, ready for burning, Stucco Mills, Ft. Dodge, Iowa	68.3	60.0	44.0
Stucco, Ft. Dodge Plaster Co., Ft. Dodge, Iowa	71.9	66.2	49.3
Baker stucco, Kansas	72.9	58.3	39.5
Kallolite stucco, Cardiff Gypsum Plaster Co., Ft. Dodge, Iowa	69.1	63.8	50.2
Baker plaster, Kansas	68.2	58.7	28.2
Mineral City wall-plaster, Ft. Dodge, Iowa	72.1	65.4	49.1
Oklahoma Cement Plaster Co., Okarche, Oklahoma	77.8	70.2	51.3
Flint wall-plaster, Iowa Plaster Association, Ft. Dodge, Iowa	72.4	64.2	48.1
Acme wall-plaster, Acme, Texas	74.6	69.2	56.6
Kallolite wall-plaster, Cardiff Gypsum Plaster Co., Ft. Dodge, Iowa	70.8	65.5	53.5
Stonewall-plaster, Ft. Dodge Plaster Co., Ft. Dodge, Iowa	72.4	66.1	54.0
Duncomb wall-plaster, Duncomb Stucco Co., Ft. Dodge, Iowa	63.8	57.8	43.6

Tensile and Compressive Strength.

Methods of testing plasters and similar products have never been standardized, and the result is that each investigator applies such tests as he may deem advisable. In general the practice has followed closely along the lines of cement-testing.

Tensile strength of plasters.—In making the experiments discussed below, Professor Marston "mixed the plaster or stucco thoroughly, by hand, with water. The mortar was then placed in standard (Am. Soc. C. E.) cement briquette molds and packed with the finger. The surface of the briquette was smoothed with a trowel. As soon as the

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* Iowa Geological Survey, vol. 12, p. 162.

briquettes were sufficiently set, which usually took about three hours, the molds were removed". Some of the briquettes were kept in air and some in water for various lengths of time, and they were finally broken in a Fairbanks cement-testing machine. Preliminary tests, using various percentages of water, showed that 30 to 35 per cent of water gave the maximum strength of briquettes. As 35 per cent gave a mixture that was more readily handled in the making of briquettes than the 30 per cent mixture, it was adopted for the final series of tests whose results follow.

A series of 220-day tests were made, but the results are of little value, because the briquettes were allowed to stand in very moist air between the 28- and 220-day periods, and therefore all showed a marked falling off in strength. For this reason the results of the 220-day tests are omitted here.

TABLE 13.

FINENESS OF PLASTERS TESTED.

	Per Cent Passing Sieve.		
	74-mesh.	100-mesh.	200-mesh.
Crystal Rock plaster	73.7	12.3	2.5
" " "	74.3	55.2	4.3
Flint plaster, fresh	66.4	58.6	55.7
" " old	81.9	68.7	52.2
German stucco	90.5	85.0	19.8

TABLE 14.

TESTS OF TENSILE STRENGTH AND EFFECT OF SAND.

	Neat.				1 Plaster, 1 Sand.				1 Plaster, 2 Sand.				1 Plaster, 3 Sand.			
	1 Day.	1 Week.	4 Weeks.	3 Months.	1 Day.	1 Week.	4 Weeks.	3 Months.	1 Day.	1 Week.	4 Weeks	3 Months.	1 Day.	1 Week.	4 Weeks.	3 Months.
Crystal Rock plaster, unsifted	228	393	445	426	87	320	368	370	55	203	212	255	35	148	145	156
Crystal Rock plaster, sifted	...	...	...	...	...	...	...	...	57	231	229	229				
Flint plaster, fresh, unsifted	135	310	402	...	104	303	362	...	64	206	203	...	39	132	139	
Flint plaster, fresh, sifted	...	...	...	...	...	...	...	...	61	233	242					
Flint plaster, old, unsifted	155	353	433	...	...	...	...	...	26	109	123					
Flint plaster, old, sifted	...	...	...	...	...	...	...	...	49	205	256					
German stucco	300	461	461	...	...	...	...	...	119	336	356	...	75	303	252	

The results of a later series of tests carried * out by Prof. Marston are given below. Most of the tests were made on fresh plaster as marketed. A few, however, noted in the table as "sifted", were made on that portion of the plaster which passes through a 100-mesh sieve. Plaster four years old was also tested, as noted in the table. All the figures given are the averages of from 3 to 15 separate tests.

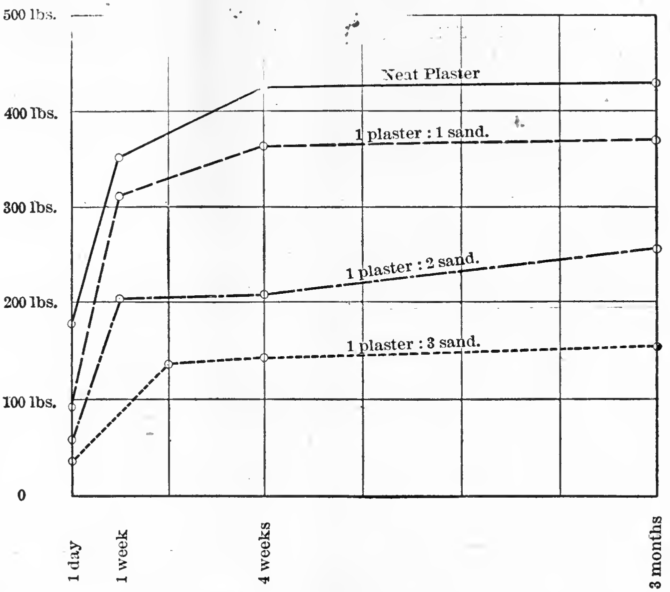

FIG. 18.—Effect of sand on tensile strength of plasters. (Marston.)

These tests appear to show † that

(*a*) Cement plasters and stuccos attain almost their full strength at the end of one week, showing little further gain at three months.

(*b*) The portion of the plaster which passes a 100-mesh sieve is stronger than the coarser portions, and the higher strength of fine plaster is shown better in sand mixtures than when tested neat.

(*c*) The value of fine grinding is further emphasized by the high results shown by the German stucco, which seems to have been the most finely ground of all, though the values of fineness given are not quite consistent.

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* Iowa Geol. Survey, vol. 12, pp. 232–235.

† The conclusions here drawn from these tests are those of the writer. For Professor Marston's conclusions, which do not entirely agree with mine, reference should be made to the original work.

TABLE 15.

RESULTS OF TENSILE TESTS OF PLASTERS, ETC.

Material.	Tensile Strength per Square Inch.			
	Kept in	1 Day.	7 Days.	28 Days.
Stucco, Fort Dodge, Iowa	Air	226	204	329
	"	219	210	438
	Water	195	139	187
	"	208	154	200
Kallolite plaster, Ft. Dodge, Iowa	Air	219	188	379
	"	186	230	245
	Water	175	185	168
	"	189	170	209
Duncomb plaster, Ft. Dodge, Iowa	Air	211	184	375
	"	208	220	360
	Water	192	172	180
	"	202	175	186
Mineral City plaster, Ft. Dodge, Iowa	Air	...	190	237
	"	...	301	437
	Water	215	203	195
	"	192	196	205
	"	195		
Stone plaster, Ft. Dodge, Iowa	Air	131	170	483
	"	144	228	470
	Water	187	163	182
	"	214	193	148
Flint plaster, Ft. Dodge, Iowa	Air	192	224	348
	"	204	217	285
	Water	188	207	158
	"	214	205	163
Acme plaster, Acme, Texas	Air	107	128	333
	"	131	175	303
	Water	82	20	151
	"	111	112	154
Stucco, Baker Stucco Co., Kansas	Air	227	236	468
	"	221	208	461
	Water	216	223	154
	"	226	201	181
Plaster, Baker Stucco Co., Kansas	Air	181	195	465
	"	134	218	286
	Water	183	196	195
	"	185	162	215

Compression tests and effects of sand.—A valuable series * of experiments were carried out during 1899–1900 by Profs. Slosson and Moudy on the compressive strength of plasters, both neat and mixed, with varying properties of sand. Most of the material used for these tests was a cement plaster manufactured at Laramie, Wyo., the tests being made before the addition of retarder to the plaster.

The material was molded into 2-inch cubes and crushed in a Riehle self-registering machine after the cubes had been exposed to the air

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* Tenth Ann. Rep. Wyoming Agric. and Mech. College, 1900.

for one week. "The sand used was obtained from the Laramie River and was composed of sharp-angled granitic fragments. It was sifted through a millimeter sieve."

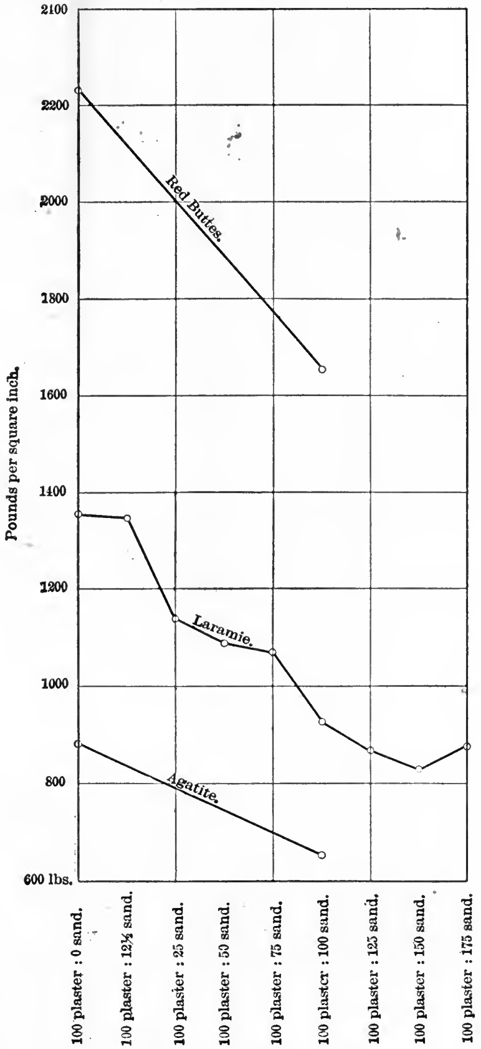

FIG. 18*a*.—Effect of sand on compressive strength of plaster.

Adhesive tests of plasters.—The adhesive tests in Table 17 were made by Prof. Marston "by taking pieces of No. 2 paving-brick from Des Moines and grinding them on the emery-wheel so as to make approximately 1-inch cubes. Each cube had one face carefully trued to give a cross-section exactly 1 inch square. These pieces of paving-brick were placed in the cement briquette molds with this true surface exactly at the middle of the mold. The plaster or stucco was placed to fill the other half of the mold, while the half in which the piece of brick was placed was filled with neat Portland-cement mortar".

TABLE 16.

EFFECT OF SAND ON COMPRESSIVE STRENGTH OF PLASTERS.

Kind of Plaster.	Parts by Weight.			Number of Tests.	Strength, 2-inch Cube.	Lbs. per Sq. In.
	Plaster.	Sand.	Water.			
Laramie plaster, no retarder. . .	100	0	56	4	5435	$1358\frac{3}{4}$
" " " " . . .	100	$12\frac{1}{2}$	56	2	5430	$1357\frac{1}{2}$
" " " " . . .	100	25	57	10	4575	$1143\frac{3}{4}$
" " " " . . .	100	50	$58\frac{7}{10}$	5	4378	$1094\frac{1}{2}$
" " " " . . .	100	75	60	7	4317	$1079\frac{1}{4}$
" " " " . . .	100	100	$61\frac{1}{5}$	6	3755	$938\frac{3}{4}$
" " " " . . .	100	125	$62\frac{1}{2}$	7	3505	$876\frac{1}{4}$
" " " " . . .	100	150	$63\frac{7}{10}$	8	3341	$835\frac{1}{4}$
" " " " . . .	100	175	65	6	3523	$880\frac{3}{4}$
Red Buttes plaster, no retarder	100	0	50	?	8945	$2236\frac{1}{4}$
" " " " "	100	100	55	?	6622	$1655\frac{1}{2}$
Agatite plaster, market sample	100	0	50	?	3550	$887\frac{1}{2}$
" " " "	100	100	55	?	2597	$649\frac{1}{4}$

TABLE 17.

ADHESIVE STRENGTH OF PLASTERS.

Material.	Adhesive Strength per Square Inch.		
	Kept in	7 Days.	28 Days.
Stucco, Ft. Dodge, Iowa	Air	87	133
" " " "	Water	87	75
Kallolite stucco, Ft. Dodge, Iowa	Air	45	115
" " " " "	Water	31	
" plaster, " " "	Air	52	102
" " " " "	Water	43	
Duncomb " " " "	Air	62	81
" " " " "	Water	. .	84
Mineral City plaster, Ft. Dodge, Iowa	Air	72	212
" " " " " "	Water	. .	84
Stone plaster, Ft. Dodge, Iowa	Air	31	80
Flint " " " "	"	64	114
" " " " "	Water	26	
Acme plaster, Acme, Texas	Air	76	103
Baker stucco, Kansas	"	. .	117
" " "	Water	98	100
" plaster, "	Air	83	105
" " "	Water	55	95
Plaster, Okarche, Oklahoma	Air	82	
" " "	Water	63	133

Rate of Set and Hardening.

A pure plaster of Paris will normally harden or set in from five to fifteen minutes after having been mixed with water. Plasters made from impure gypsum will be considerably slower setting than this, setting usually in from one to two hours.

When plasters are to be used for structural work, they must be either naturally slow-setting, like some of the cement plasters, or be made slow-setting by proper treatment. Retarders are therefore used at plaster-plants in preparing their product for the market. Occasionally, though rarely, a plaster will be naturally too slow setting for the particular use to which it is to be applied. In this case an accelerator must be used.

Theory of the action of retarders and accelerators.—As will be noted later, the materials most commonly used as retarders are glue, tankage, and other organic and uncrystallized materials, while accelerators are usually inorganic and crystallized. This fact suggested a theory as to the cause of the action of accelerators and retarders. The theory, as set forth * by its originator, Dr. Grimsley, is as follows:

Dr. Grimsley assumes that the set of plaster is due to the presence of a few small crystals which have escaped dehydration during burning and which set the example, so to speak, to the other crystals to form; and, further, that the strength of the set material is due to the formation of a mass of interlacing crystals. The action of retarders and accelerators is therefore explained by assuming that "any substance [added to the water with which the calcined plaster is mixed, or to the dry plaster] which will keep the molecules apart or from too close contact will retard the setting. Such substances are dirt or organic matter that is not of a crystalline character". On the other hand, the action of accelerators is ascribed to the fact that, being of crystalline character, they induce crystallization in the plaster to which they are added.

It is probable that the researches of Rohland on the effect of various substances on the speed of hydration of plasters, Portland cement, etc., are directly applicable to the question on hand. In summing up his conclusions, Rohland decided that substances which increase the solubility of the cementing material accelerate its speed of hydration, while substances which decrease the solubility of the cementing material retard its hydration.

Materials used as retarders.—The materials used as retarders are usually of animal or vegetable origin. Glue, sawdust, blood, and packing-

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* Vol. 5, Reports Geological Survey Kansas, pp. 167, 168.

house tankage are some of the retarders most commonly used. Many "patent" retarders are also on the market, most of which are based on one or more of the organic materials noted above.

In the course of the experiments by Slosson and Moudy, recorded below, an effort was made to obtain a cheap and satisfactory home-grown retarder. With this in view a common western cactus (*Opuntia platycarpia*) was dried and ground. The common malva (*Malvastrum coccineum*) was also prepared in a similar manner. The retarders thus made were light green in color, possessed no disagreeable odor, and when used in the proportion of 2 pounds of retarder to a ton of plaster gave excellent results. It is probable that many other plants, dried and ground in similar fashion, would form satisfactory retarders.

Effect of retarders on strength of plasters.—The following table * contains the results of compression tests by Profs. Slosson and Moudy on plasters containing various amounts of retarder. It appears to show conclusively that the compressive strength (and inferentially the tensile strength) of plasters decreases as the amount of retarder increases.

TABLE 18.

EFFECT OF RETARDERS ON STRENGTH OF PLASTERS.

	Pounds of Retarder per Ton of Plaster.	Crushing Strength in Pounds.	
		2-inch Cube.	Per Square Inch.
Laramie plaster.	0	5435	1358.75
" "	2	4065	1016.25
Red Buttes plaster. . .	0	8945	2236.25
" " " . . .	2	7192	1798.00
" " " . . .	4	6480	1620.00

In making the tests the finely ground retarder was accurately weighed and thoroughly mixed with the dry plaster. Water was then added and the mixture, placed on a glass plate, was fashioned into a pat about 4 inches in diameter. For determining the setting time two needles were used, each $\frac{1}{12}$ inch in diameter, one loaded with a weight of $\frac{1}{4}$ lb., the other with a weight of 4 lbs. The time when the more lightly weighted needle ceased to make a decided impression on the surface of the plaster pat is reported as "initial set", and when the more heavily weighted needle was supported without indenting the plaster is reported as "final set".

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* Tenth Ann. Rep. Wyoming Agric. and Mech. College.

TABLE 19.

EFFECT OF VARIOUS RETARDERS ON RATE OF SET.

Kind of Plaster.	Kind of Retarder.	Pounds Retarder per Ton.	Initial Set, Minutes	Final Set, Minutes	Remarks.
Laramie.	None.	0	145	225	
“	Market sample.	?	280	335	
“	“ “	?	...	720	
“	Wymore.	1	320	380	
“	“	2	365	430	
“	“	4	520	655	
“	“	6	590	690	Cracked a little.
“	“	8	785	...	Never hardened.
“	Webster City.	2	350	390	
“	“ “	4	535	645	Cracked somewhat.
“	“ “	6	735	...	Cracked badly.
“	“ “	8	755	...	Did not set.
“	Swift's, Chicago.	1	260	310	
“	“ “	2	265	310	
“	“ “	4	280	315	
“	“ “	6	290	320	
“	Swift's, Kansas City	1	...	310	
“	“ “ “	2	215	250	
“	“ “ “	2	255	315	
“	“ “ “	4	250	315	
“	“ “ “	4	255	310	
“	“ “ “	6	250	300	
“	“ “ “	6	215	255	
“	Cactus.	2	245	285	
“	“	2	275	320	
“	“	4	250	310	
“	“	6	290	340	
“	Malva.	2	245	295	
“	“	4	280	295	
“	“	6	275	310	
“	Glucose.	6	290	375	
“	Clay (bentonite).	6	240	320	
“	“ “	10	260	330	
Red Buttes stucco	None	0	30	50	
“ “ “	“	0	24	42	
“ “ “	“	0	20	32	
“ “ “	Wymore.	2	60	105	
“ “ “	“	8	270	...	Did not set.
Red Buttes plaster.	None	0	50	80	
“ “ “	Wymore.	2	285	345	
“ “ “	“	8	505	...	Soft-cracked.
“ “ “	Market sample.	?	310	375	
Agatite plaster.	“ “	?	240	305	

Use of accelerators.—In making dental plaster and plaster for certain other purposes an extremely rapid set is desirable. For this purpose many crystalline salts are available, common salt being one of the best accelerators known.

TABLE 20.

EFFECT OF ACCELERATORS ON RATE OF SET.

Kind of Plaster.	Kind of Accelerator.	Pounds Accelerator per Ton.	Time of Set, in Minutes.	
			Initial Set.	Final Set.
Laramie.	None.	0	145	225
"	Common salt.	6	55	150
"	Sodium sulphate.	6	150	170
"	Sodium carbonate.	6	145	170

References on properties and tests of plasters.—The following brief list covers the principal papers on this subject.

Bailey, E. H. S. On the chemistry of gypsum, plaster of Paris, and cement plaster. Vol. 5, Reports Kansas Geological Survey, pp. 134–170.

Marston, A. Preliminary tests of stucco and plaster made by the Civil Engineering Department of Iowa State College. Vol. 12, Reports Iowa Geological Survey, pp. 224–235. 1902.

Slosson, E. E., and Moudy, R. B. The Laramie cement plaster. 10th Ann. Rep. Wyoming, College Agriculture and Mechanics, 1900.

Anon. Tests for plaster of Paris. Stone, vol. 25, pp. 331–334. 1903.

Hardening gypsum and plaster.—The following methods of hardening an ordinary plaster have been recently recommended:*

(1) Two to four per cent of finely ground marshmallow-root are intimately mixed with powdered plaster and the mixture kneaded to a dough with 40 per cent of water. The resulting mass resembles a stiff clay, hardens in about an hour, and finally becomes hard enough to cut, file, or bore. A harder and tougher mass may be obtained by increasing the quantity of marshmallow-root to 8 per cent. Gum, dextrin, or glue may be substituted for the marshmallow-root if more convenient. If the objects are to be exposed to high temperatures shellac may be used.

(2) Six parts of gypsum are mixed with one part of freshly slaked lime and the mixture is soaked with a concentrated solution of magnesium sulphate. In preparing this mixture, too much gypsum must not be poured into the water, and the mixture must be stirred quickly so that lumps do not form. The smaller the quantity of water used the thicker and firmer is the cement. The porosity caused by the gradual loss of water can be obviated by soaking the objects in a solution of ozocerite or wax in oil of turpentine, varnish, or hot tar, or by coating them with shellac.

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* Journ. Soc. Chem. Industry, vol. 21, p. 347.

CHAPTER IV.

FLOORING-PLASTERS AND HARD-FINISH PLASTERS

The two groups of plasters to be considered in this chapter agree (1) in being prepared by burning gypsum at a higher temperature than is employed in the manufacture of plaster of Paris and " cement " plasters, and (2) in being products which; for plasters, set rather slowly but finally take on great hardness. Because of these last properties, the flooring-plasters and hard-finish plasters are available for certain uses to which ordinary plasters are ill adapted. So much for the resemblances between the two groups. Their points of difference are, that the flooring-plasters are prepared by simple burning at high temperatures, while the hard-finish plasters are produced by a *double* burning, with the additional use of chemicals.

Neither product is made to any extent in the United States, though a considerable quantity of hard-finish plasters are imported every year. The data obtainable as to processes of manufacture are scanty, and the descriptions published are often contradictory, so that it has been difficult to prepare a satisfactory account of these products. It is believed, however, that the descriptions given below contain no errors of importance.

Flooring-plasters.

The flooring-plasters (" Estrichgips " of German reports) include those plasters made by calcination of a relatively pure gypsum at temperatures of 400° F. or higher.

In the literature of gypsum and plaster it is often stated that gypsum, burned at temperatures exceeding 400° F., yields a completely dehydrated product—an artificial anhydrite—which is entirely valueless as a structural material, because it has completely lost its property of recombining with water. This statement is, however, erroneous, for plasters burned at such temperatures are regularly made and used. They set with extreme slowness, however, and require very fine grinding.

Composition of flooring-gypsum.—Until very recently no satisfactory discussion of this phenomenon had been attempted, and the few published accounts of the manufacturing processes employed were contradictory as to temperatures reached, composition of product, etc. Fortunately, however, a detailed account * of the chemical changes involved was published during 1903 by Van't Hoff in the Transactions of the Berlin Academy of Sciences. As this paper is practically inaccessible to the American engineer or manufacturer, a translation † is here appended:

"As a complement to the investigations on gypsum and anhydrite we have turned our attention to a kindred product, usually designated by the term hydraulic gypsum or floor-gypsum (Estrichgips). It is obtained by burning natural gypsum, $CaSO_4.2H_2O$. When natural gypsum is worked up into stucco gypsum $(CaSO_4)_2.H_2O$, in the process called cooking, the temperature of 120°–130° C. is not exceeded; but in the preparation of floor-gypsum higher temperatures are applied. Accordingly the product is free from water, but we are not in this case dealing with dead-burned gypsum, since the capacity to bind water has not yet been lost. However, the time required for setting is much longer than in the case of stucco gypsum; the latter, as every one knows, hardens in about a quarter of an hour, while the hardening of the floor-gypsum takes place only after some days, and the complete absorption of the amount of water theoretically required may take weeks.

"**Composition and structure of floor-gypsum.**—Some indications in literature suggested that in this floor-gypsum we are dealing with a basic sulphate. Accordingly a commercial floor-gypsum was first analyzed; it showed 38.6% CaO, 54.3% SO_3, and foreign ingredients.

"From this the ratio of $CaO:SO_3$ in molecules is found to be 1.01:1. The product therefore is calcium sulphate anhydrite without any notable surplus of lime. The fact that but slight quantities of lime are present was also demonstrated in another way: 1.134 gr. of the substance was boiled for 3½ hours with 75 ccm. of 0.425 normal potassium hydroxide, whereupon everything went into solution except slight impurities. To titrate back, 47.8 ccm. of potassium hydroxide were then required, which indicates a content in free lime corresponding to $125-(75+47.8)=2.2$ ccm. in weight 0.026 gr. or about 2 per cent of the whole.

"Having ascertained this composition, it only remained to answer the question as to the relation which the floor-gypsum bears to the two known modifications of anhydrous calcium sulphate, namely, the natural and the soluble anhydrite. The difference between these two lies in this, that the former is practically incapable of binding water, that is to say, it does so with extreme slowness, and thus acts like dead-burned gypsum, while the soluble anhydrite takes up water even more rapidly than stucco gypsum does.

"A first hint was obtained from the microscopic examination. As shown by this, the floor-gypsum consists for the most part of distinctly

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* Van't Hoff and Just, G. Der hydraulicshe oder sogennante Estrichgips. Sitzungsberichte der Kgl. Preuss. Akad. der Wissenschaften, 1903, B. I, pp. 249–258.

† For this translation the writer is indebted to Dr. Robert Stein, formerly of the U. S. Geological Survey.

recognizable needles; these have the form of the crystalline plaster of Paris $(CaSO_4)_2H_2O$. As floor-gypsum contains no water, the needles are evidently pseudomorphs after plaster of Paris. It may be added that stucco gypsum, though consisting essentially of half hydrate is far from showing the crystalline development of the floor-gypsum.

"In view of this striking crystalline condition, we directed our investigation not only to the influence of the burning temperature but also to the possible influence of this factor (crystalline form).

"To get an idea of the hardening property, observation is naturally directed first to the process as carried out in practice, and we did not fail to follow it on a small scale. However, we soon felt the need for a process which would enable this hardening to be traced with greater accuracy quantitatively. For this purpose we used the change of volume in hardening and the weighing of the quantity of water taken up.

"1. **Change of volume on hardening.**—When the practicability of the volume process was first tested in the case of stucco gypsum, a great irregularity manifested itself, which was not observed in the case of floor-gypsum. Hence we might pass those preliminary experiments without mention did they not furnish the explanation of the well-known fact that the hardening of gypsum, though accompanied by contraction, nevertheless may lead to the breaking of the vessels in which it takes place.

"The apparatus consisted of a small flask with narrow neck; the sample of gypsum, having been weighed, is introduced, and then a closed capillary is sealed to it, which at a short distance above the flask bears a lateral branch with stop-cock. By means of this the apparatus is connected with the air-pump, and, after evacuation, is placed in a thermostat filled with gypsum-water at 25°. The stop-cock is opened and gypsum-water is allowed to flow in. Gpysum-water is used instead of ordinary water, in order to avoid the change of volume accompanying the solution of the gypsum. After closing the stop-cock and breaking off the upper end of the capillary, the reading of the level in the latter may be performed by means of a millimeter scale one minute after the introduction of the gypsum-water.

"The following table shows the result of such an observation:

Time in Minutes.	Height in Millimeters.	Time in Minutes.	Height in Millimeters.
2	540	38	374
5	522	41	375
8	486	44	376
11	448	47	377
14	408	50	378
17	385	53	380
20	374	56	381
23	371	59	383
26	370	62	387
29	370	65	388
32	371	166	413
35	372	870	438

"On the whole, therefore, a contraction takes place, as is required, in fact, by the molecular volumes at 25°:

	Molecular Weight.	Specific Gravity.	Molecular Volume.
$CaSO_4\frac{1}{2}H_2O$......	145.17	2.75	52.79
$CaSO_42H_2O$......	172.19	2.32	74.22
H_2O............	18.016	0.997	18.07

Hence for

$$CaSO_4\tfrac{1}{2}.H_2O+1\tfrac{1}{2}H_2O=CaSO_42H_2O, \qquad \varDelta V=-5.68.$$

However, after a rather large contraction (from 540 to 370) a transient expansion (from 370 to 438) manifests itself.

"Although this peculiar behavior suggested the transient formation of an intermediate product, yet all attempts to isolate such a product were in vain. The explanation is found in another way: the solubility of the stucco gypsum ($CaSO_4.\frac{1}{2}H_2O$) is much greater than that of normal gypsum (according to Marignac one part of $CaSO_4$ in the first form dissolves in 110 parts of water, while of the second form one part dissolves only in 479 parts of water at 24°); thus the solution first formed is oversaturated with gypsum and precipitates the latter. Now, as shown by direct experiment, this process is accompanied by considerable expansion; in the same apparatus, when 0.54 gram of gypsum was thrown down from the oversaturated solution, there was a rise of 78 mm. in the scale, that is to say, quite comparable with the above value (conversely the solution of gypsum was accompanied by a contraction). Undoubtedly connected with this process is the sweating-out, which is occasionally observed in casts of stucco gypsum. While, therefore, the volume method of ascertaining the process of the hardening of stucco gypsum is to be rejected, a satisfactory regularity appears in the case of floor-gypsum, as shown by the following table:

Time.	Level in mm.	Time.	Level in mm.
1 minute	405	8 days 6 hours	322
6 minutes	395	9 " 22 "	314
11 "	393	11 " 6 "	309
16 "	392	14 " 0 "	301
45 "	390	15 " 4 "	297
100 "	388	15 " 22 "	295
430 "	383	17 " 6 "	292
1 day 0 hours	370	18 " 7 "	290
1 " 7 "	365	18 " 23 "	288
3 days 0 "	349	20 " 0 "	285
4 " 4 "	342	21 " 0 "	282
5 " 0 "	338	22 " 8 "	279
7 " 0 "	327	53 " 0 "	243

"The observed diminution of volume corresponds to expectation, regard being had to the molecular volumes at 25°:

	Molecular Weight.	Specific Gravity.	Molecular Volume.
$CaSO_4$	136.16	2.97	45.85
$CaSO_4 2H_2O$	172.19	2.32	74.22
H_2O	18.016	0.997	18.07

Hence for

$$CaSO_4 + 2H_2O = CaSO_4 2H_2O, \qquad \Delta V = -7.77.$$

"The observed diminution of volume satisfied this requirement even quantitatively, inasmuch as 11.63 grams of floor-gypsum caused an expansion of 0.63 c.c., that is to say, 0.054 per gram, while calculation gives 0.057. It may be added that the water content of the mass formed (20.6 per cent) corresponded to the total transformation into gypsum (20.9 per cent).

"With the aid of this method we traced the influence which the burning temperature has on the setting capacity. In particular we investigated the contradictory statements whether the formation of the gypsum capable of setting takes place at a temperature higher than that at which dead-burning ensues or whether with rising temperature the binding capacity is gradually lost. This determination is important, for according to the above statement a dead-burned gypsum, and probably also the natural anhydrite, would acquire binding capacity by appropriate burning. Let it be stated at once that, so far as our observations go, the binding capacity decreases regularly with increasing burning temperature.

"In this respect we had previously found that an anhydrite prepared at 100° hardens even more quickly than stucco gypsum. A real burning can only be spoken of above 190°, for it is only above that temperature that the water develops out of half-hydrate at a technically utilizable rate. Hence we first of all heated samples of well-crystallized half-hydrate (obtained from gypsum with nitric acid) at 200° and 300° for ten hours each. The volume experiment showed in the case of the latter sample a decrease of binding capacity:

200°; 2.624 gr. Capillaries: 1 mm. = 0.00382 c.c.

Time	1 min.	6 min.	26 min.	85 min.	172 min.	23½ hrs.	46 hrs.	∞
Level in mm.	491	481	472	464	463	459	456	456

300°; 2 gr. Capillaries: 1 mm. = 0.00323 c.c.

Time	1 min.	20 min.	28 min.	86 min.	122 min.	7 hrs.	21 hrs.	∞
Level in mm.	506	500	499	496	495	493	487	472

"It appears that the gypsum heated at 300° sets more slowly than that which has been heated at 200°; after 23½ hours, for example, 93 per cent were set in the former case, in the latter after 21 hours only 56 per cent.

"As these results rendered it probable that the floor-gypsum is not a product of a temperature higher than the dead-burning temperature, but that dead-burning ensues only after the formation of floor-gypsum, we heated a floor-gypsum for 10 hours at 400°. The setting capacity had been thereby considerably decreased:

Unheated sample, 2 gr. Capillaries: 1 mm. = 0.00398.

Time.	1 min.	8 min.	44 min.	6 hrs.	23 hrs.	6 dys.	13 dys.	∞
Level in mm. .	543	543	541	540	539	532	528	519

Heated sample, 2 gr. Capillaries: 1 mm. = 0.00323.

Time.	1 min.	12 min.	17 hrs.	6 dys.	13 dys.	∞
Level in mm.	527	526	523	518	514	494

"Thus in the first case 67 per cent were set after thirteen days, in the second case only 39 per cent.

"On inquiring for a sample of dead-burned gypsum from the same source, it appeared that it was a very finely crystallized half-hydrate with the quantity of water corresponding to the hydrate (7.3 per cent instead of 6.2 per cent).

"A brief ignition of the commercial floor-gypsum in the platinum crucible finally led to dead-burning, and the sample did not harden even after weeks.

"2. **Increase of weight on hardening.** Exactly the same result, that is to say, a gradual decrease of the binding capacity with increasing burning temperature, was obtained on following the amount of water absorbed in a moist atmosphere. For this purpose the samples were placed on watch-crystals under a globe alongside of water. Well-crystallized half-hydrate, obtained from gypsum with nitric acid, was heated for ten hours at 200°, 300°, and 400° respectively, and thereupon the absorption of water was followed by means of weighing. The result is contained in the following table:

Time.	200° in Gr.	Δ_1	300° in Gr.	Δ_1
0	0.5		0.5	
1 hour 0 minutes.	0.5027	0.0027	0.5015	0.0015
3 hours 40 "	0.5069	0.0042	0.5039	0.0024
6 " 10 "	0.5104	0.0035	0.5060	0.0021
22 " 5 "	0.5413	0.0309	0.5240	0.0180
28 " 0 "	0.5504	0.0309	0.5266	0.0026
45 " 30 "	0.5665	0.0161	0.5381	0.0115
52 " 0 "	0.5670	0.0005	0.5384	0.0003
69 " 30 "	0.5760	0.0090	0.5440	0.0056
95 " 30 "	0.5868	0.0108	0.5521	0.0081
131 " 30 "	0.6016		0.5688	

Time.	300° in Gr.	Δ_1	400° in Gr.	Δ_1.
0	0.5		0.5	
1 hour 30 minutes.....	0.5061	0.0061	0.5062	0.0062
5 hours 30 "	0.5100	0.0039	0.5090	0.0028
22 " 50 "	0.5239	0.0139	0.5187	0.0097
48 " 50 "	0.5410	0.0171	0.5238	0.0051
94 " 50 "	0.5584	0.0174	0.5320	0.0082

"By this method the floor-gypsum, when heated for ten hours at 400°, showed an unmistakable loss of binding capacity:

Time.	Commercial Floor-gypsum.	Δ_1.	Commercial Floor-gypsum Heated to 400°.	Δ_2.
0	0.5		0.5	
1 hour 0 minutes.....	0.5031	0.0031	0.5035	0.0035
2 hours 0 "	0.5046	0.0015	0.5046	0.0011
9 " 0 "	0.5093	0.0047	0.5082	0.0036
23 " 40 "	0.5130	0.0037	0.5107	0.0025
72 " 30 "	0.5170	0.0040	0.5134	0.0027

"While the determination of the influence of temperature was possible both by dilatometric methods and by weighing, the determination of the influence of crystalline structure was rendered impossible in both cases by the fact that we had to deal with an uneven surface. Nevertheless the orienting experiments showed that the half-hydrate crystalline form, if retained, exerts an influence in that it materially retards dead-burning; in other words, an amorphous gypsum, by burning, loses the setting capacity much more easily than a half-hydrate of well-developed crystalline structure.

"To determine this fact more accurately three forms of gypsum were used:

"1. Well-developed half-hydrate obtained by nitric acid.

"2. Alabaster gypsum of commerce, with little crystalline development.

"3. Gypsum obtained by treating a stucco gypsum with an excess of water, leading to a development of exceedingly fine needles, which were very apt to lose water and in such case show nothing of the half-hydrate form.

"These samples were heated for about five minutes on a gentle-red glow in the platinum crucible and then sealed up with a slight excess of water in a test-tube and left to harden. After about twenty-four hours, sample No. 1 had already become much harder and showed gypsum crystals under the microscope; the other two samples had remained perfectly soft and showed no change under the microscope. After three days the first sample had been completely hardened and entirely transformed into gypsum crystals. The alabaster gypsum is still soft, but may be slightly harder than the third sample, which is entirely unaltered. Under the microscope the alabaster gypsum after twelve days showed several gypsum crystals, while the third sample showed only scattering ones.

"The essential result of the investigation, therefore, is, that in the heating of gypsum after total dehydration, which occurs at about 190°, the capacity to bind water is at first retained, and is only gradually lost, either by more intense or by longer heating. The retention of the crystalline form, which is probably due to burning without previous division into small bits, checks this so-called dead-burning, and is therefore of technical importance. We found no evidence to support the statement that, after dead-burning, a new binding capacity appears at a high temperature, in which case even the natural anhydrite would be suitable for burning floor-gypsum."

Methods of manufacture.—Flooring-gypsum is, therefore, a pure plaster, entirely free from water. It is manufactured by burning pure gypsum, broken into lumps but not finely crushed, in a vertical kiln. The fuel, usually coal, is burned on a grate set at one side of the kiln, and the hot gases pass directly through the mass of gypsum, though neither fuel nor ashes come into direct contact with it. The temperature reached is, according to Wilder, about 500° C. The gypsum must not be exposed to this temperature for more than four hours, for a longer heating would deprive it entirely of its setting properties, as noted by Van't Hoff in the paper presented above.

Uses of flooring-gypsum.*—As its name denotes, flooring-gypsum (Estrichgips) is extensively used in Germany for floors, giving a very hard and durable surface. As the material attains this hardness only when it is protected from moisture during setting, care must be taken to give it a suitable foundation. If the material dries unevenly or very rapidly cracks will appear on its surface. In this case the floor should be covered with water until the surface is soft and the cracks closed, after which it is allowed to dry again. After standing about twelve hours and becoming fairly hard the floor is pounded with wooden mallets and smoothed with trowels.

Pure flooring-plaster gives the best results for hardness, but for economy it may be used in a mixture of two parts plaster to one part sand, ashes, etc. A cubic meter of hardened flooring-gypsum weighs about 2000 lbs., equivalent to a weight of about 57 lbs. per cubic foot.

Flooring-plasters are manufactured on a fairly large scale in Germany, but have not been made or utilized in England or the United States.

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* The data on the uses of flooring-gypsum are largely taken from Wilder's paper, cited previously.

Under the next group (Hard-finishing Cements), however, will be found descriptions of a number of products which have been manufactured in these latter countries and which are very closely related to the dead-burned plasters. The only difference in technology between the two groups is that while the flooring-plasters are prepared from pure gypsum the hard-finishing cements are prepared from gypsum to which alum or some similar material has been added.

Hard-finish Plasters.

The materials grouped under this name include those plasters which owe their hardness and slow set not only to being burned at high temperatures, but to the fact that they have been treated with alum or other chemicals during manufacture. As thus defined, the hard-finish plasters include the various materials known commercially as "Keene's cement", "Parian cement", "Mack's cement", etc.

Keene's cement.—The most prominent representative of the group of hard-finishing cements is that known to the trade as Keene's cement. Originally manufactured under English patents which have now expired, the term "Keene's" is applied by various manufacturers to their product, in the same manner as the term "Portland" has become generalized. Large quantities of Keene's cement are annually imported, while its manufacture in the United States has been of late years successively begun.

Keene's cement is sharply distinguished from the other members of the group of hydrate cements (or "plasters"), not only by the properties of the product, but by its method of manufacture. In its preparation a very pure gypsum is calcined at a red heat, the resulting dehydrated lime sulphate is immersed in a bath of alum solution and, after drying, is again burned at a high temperature. After this second burning the product is finely ground and is then ready for the market. This sketch of the process is a general outline of the methods used, and in the essentials is followed in all plants, though slightly modified at different plants according to the experience gained by each manufacturer.

The gypsum used should be as pure as possible, and especially it should be free from such impurities as might tend to discolor the product, which should be a pure white. Nova Scotia gypsum has been tried and, for some reason, found to be unsatisfactory. Even the Virginia gypsum, which on analysis shows but a trace of iron oxide, is not entirely satisfactory; for on heating to the temperature necessary for the manufacture of Keene's cement, minute red streaks appear in the lumps of gypsum. The following analyses show the composition of gypsum from Virginia and Kansas, both of which have been used in the preparation of a domestic Keene's cement:

	Kansas.	Virginia.
Lime sulphate	77.46	99.58
Water	20.46	
Iron and aluminum oxides	0.10	0.036
Silica and insoluble	0.19	0.116
Magnesium carbonate	0.34	0.221
Lime carbonate	1.43	

It will be seen that both materials are very pure gypsums, and that there is no apparent reason why the Virginia material should not be as satisfactory as that from Kansas.

The calcination of the product is usually carried on in small vertical kilns closely resembling those which are in common use for lime-burning. These kilns are charged with alternating layers of fuel (usually coal) and lump gypsum. Small rotary kilns have been used experimentally, but have not proven successful, as the calcined product from a rotary kiln is discharged in small fragments which cannot be treated satisfactorily in the alum-bath. After burning to a red heat the gypsum is submitted to the action of a 10 per cent alum solution. It is then recalcined and finally ground in emery-mills.

The product is a very finely grained white powder. On the addition of water this cement hardens, but the hardening is slow relative to that of other plasters. Another peculiarity of the material is that even after the hardening has commenced, the partly set cement may be reworked with water and will take its set just as satisfactorily as if the process of hardening had not been interrupted.

An analysis of a Keene's cement manufactured in Kansas is given in "Tests of Metals, etc., at Watertown Arsenal, 1897", p. 403:

Silica (SiO_2)	tr.
Alumina (Al_2O_3)	tr.
Iron oxide (Fe_2O_3)	
Lime (CaO)	42.04
Magnesia (MgO)	tr.
Sulphur trioxide (SO_3)	56.54
Carbon dioxide (CO_2)	1.37

According to a circular issued by the sales-agent for one brand the following tests of two brands of Keene's cement were made by Lathbury and Spackman. The table below shows the tensile strength obtained, in pounds per square inch, at the end of seven days.

TABLE 21.

TENSILE STRENGTH OF KEENE'S CEMENT.

Maker.	Grade.		No. 1.	No. 2.
	Superfine.	Coarse.		
Improved Keene Cement Co., Long Island City, N. Y.	548 lbs.	606 lbs.	680 lbs.	693 lbs.
J. B. White & Bro., London, England. .	405 "	511 "		

An American Keene's cement made in Kansas was tested in 1892 by O. S. Carll for tensile strength with the following results. The cement was mixed neat, with enough water to make a stiff plaster.

TABLE 22.

TENSILE STRENGTH OF KEENE'S CEMENT.

	24 Hours.	7 Days.
Specimen No. 1.	374 lbs.	630 lbs.
" " 2.	325 "	698 "
" " 3.	402 "	678 "
Average.	367 lbs.	669 lbs.

Mack's cement * consists of dehydrated gypsum (flooring-plaster) to which 0.4 per cent of calcined sodium sulphate (Na_2SO_4, Glauber's salts) or potassium sulphate (K_2SO_4) has been added. "This cement is unusually hard and durable, sets quickly and unites minutely with the material on which it is placed. It is used as a covering for wire mesh on walls and ceilings, as well as for floors, and may be mixed with sand or ashes. Its surface is but slightly porous and for this reason absorbs but little oil when covered with paint."

References on dead-burned and hard-finish plasters.

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* Wilder, F. A. Gypsum industry of Germany, p. 208, vol. 12, Reports Iowa Geol. Survey. 1902.

CHAPTER V.

STATISTICS OF THE GYPSUM AND PLASTER INDUSTRIES.

THE statistics presented in this chapter are those collected by Mr. G. I. Adams, of the U. S. Geological Survey, for the annual report on " Mineral Resources of the United States " issued by that organization. They have, however, been condensed and rearranged in order to better serve the purposes of this volume.

Total Use of Gypsum in the United States.

The total amount of gypsum used in the United States for the four years 1900–1903, inclusive, is given in the following table. The total given in the last column of this table includes the gypsum imported as well as that produced in the country.

TABLE 23.

TOTAL IMPORTS AND PRODUCTION OF GYPSUM.

Year.	Produced in U. S. Short Tons.	Imported.* Short Tons.	Total Tons.
1900.....	594,462	229,432	823,894
1901.....	633,791	223,381	857,172
1902.....	816,478	290,858	1,107,336
1903.....	1,041,704	323,431	1,365,135

* In the Survey report above quoted the imports are given in long tons. They have here been reduced to tons of 2000 lbs.

This total amount of gypsum was distributed about as follows to the two principal uses. The term calcined plaster as here used includes all the grades of plaster of Paris, cement plaster, wall-plaster, hard-finish plasters, etc.

TABLE 24.

USES OF GYPSUM.

Year.	Calcined.	Used Crude as Fertilizer.
1900......	742,733	81,161
1901......	729,445	127,727
1902......	965,090	142,246
1903......	1,216,622	148,513

TABLE 25.

GYPSUM PRODUCTION IN THE UNITED STATES, CLASSED BY USES, 1890–1903.

Year.	Total Quantity Produced.	Sold Crude.			Ground into Land-plaster.			Calcined into Wall-plaster and Plaster of Paris.				Total Value.
		Quantity.	Value.	Average Price per Ton.	Quantity.	Value.	Average Price per Ton.	Weight before Calcining.	Calcined Plaster Produced.	Value.	Average Price per ton.	
	Short tons	Short tons			Short tons			Short tons	Short tons			
1890	182,995	18,742	$19,148	$1.02	56,525	$143,014	$2.53	107,728	79,257	$412,361	$5.20	$574,523
1891	208,126	18,574	28,690	1.54	51,700	117,356	2.27	137,852	110,006	482,005	4.38	628,051
1892	256,259	58,080	80,797	1.39	47,668	106,247	2.23	150,511	106,141	508,448	4.79	695,492
1893	253,615	42,808	71,860	1.68	50,408	106,365	2.11	160,399	122,937	518,390	4.22	696,615
1894	239,312	34,702	56,149	1.62	41,996	95,944	2.28	162,614	127,158	609,626	4.79	761,719
1895	265,503	26,624	37,837	1.42	35,079	85,355	2.43	203,800	150,801	674,255	4.47	797,447
1896	224,254	17,302	19,134	1.11	27,354	59,749	2.18	179,598	137,505	494,461	3.60	573,344
1897	288,982	23,164	27,020	1.17	31,562	67,083	2.13	234,256	180,935	661,761	3.66	755,864
1898	291,638	5,758	7,200	1.25	40,929	90,777	2.22	244,951	190,083	657,303	3.46	755,280
1899	486,235	58,352	66,762	1.14	50,033	100,797	2.01	377,850	286,227	1,119,521	3.91	1,287,080
1900	594,462	35,479	44,127	1.24	45,682	82,806	1.81	513,301	396,284	1,500,270	3.79	1,627,203
1901	633,791	68,669	71,773	1.05	59,058	109,551	1.85	506,064	399,686	1,325,317	3.31	1,506,641
1902	816,478	81,455	93,914	1.15	60,791	106,237	1.75	674,232	539,387	1,889,190	3.50	2,089,341
1903	1,041,704	73,912	87,608	1.19	74,601	154,945	2.08	893,191	742,543	3,550,390	4.77	3,792,943

Production in the United States, by Uses, 1890–1903.—In Table 25, the gypsum production of the United States is given for the years 1890 to 1903 inclusive, classed according to uses as accurately as possible. It will be seen that the amount ground up and sold as land plaster has increased but slightly during the period covered by the table. The production of calcined plaster, on the other hand, was almost seven times as great in 1903 as in 1890.

Production in the United States, by States and classes of product, 1902–1903.—At present the gypsum industry is carried on commercially in twenty-two states and territories, which are named in the order of their importance as producers: Michigan, New York, Iowa, Texas, Ohio, Oklahoma, Kansas, Wyoming, Colorado, Utah, Virginia, California, South Dakota, Nevada, Montana, Oregon, and New Mexico. The other five states do not produce gypsum, but contain large plants to which the raw material is shipped from other states and from foreign countries, and converted into wall-plaster and plaster of Paris.

In table 26, which shows the production of gypsum by states for 1902 and 1903, it has been necessary to combine the output of certain states in which there are less than three producers in order to protect individual statistics.

TABLE 26.

PRODUCTION OF GYPSUM IN THE UNITED STATES IN 1903, BY STATES.

State or Territory.	Total Quantity.	Sold Crude.		Ground into Land-plaster.		Calcined into Wall-plaster and Plaster of Paris.			Total Value.
		Quantity.	Value.	Quantity.	Value.	Before Calcining.	After Calcining.	Value.	
	Short tons.	Short tons		Short tons		Short tons	Short tons		
California, Ohio, and Virginia.	103,392	1,337	$2,531	13,065	$34,760	88,990	74,158	$429,822	$467,113
Colorado and Wyoming.	33,549	....	....	100	500	33,449	27,874	132,847	133,347
Iowa, Kansas, and Texas.	307,102	9,208	14,861	2,976	6,242	294,918	244,072	1,065,942	1,087,045
Michigan.	269,093	52,565	51,900	18,409	27,949	198,119	165,122	621,063	700,912
New York	137,886	9,304	15,439	37,850	77,392	90,732	75,613	369,552	462,383
Oklahoma.	69,158	698	877	1	2	68,459	57,049	233,742	234,621
Other states	121,524	800	2,000	2,200	8,100	118,524	98,655	697,422	707,522
Total.	1,041,704	73,912	87,608	74,601	154,945	893,191	742,543	3,550,390	3,792,943

PRODUCTION OF GYPSUM IN THE UNITED STATES IN 1902, BY STATES.

State or Territory.	Total Quantity.	Sold Crude.		Ground into Land-plaster.		Calcined into Wall-plaster and Plaster of Paris.			Total Value.
		Quantity.	Value.	Quantity.	Value.	Before Calcining.	After Calcining.	Value.	
	Short tons.	Short tons		Short tons		Short tons	Short tons		
California, Ohio, and Virginia.	101,545	2,360	$6,790	16,357	$35,450	82,828	66,263	$248,153	$290,393
Colorado and Wyoming.	16,051	....	....	....	....	16,051	12,841	73,372	73,372
Iowa, Kansas, and Texas.	295,769	957	1,180	4,331	6,497	290,481	232,385	799,678	807,355
Michigan.	240,227	68,885	70,460	13,022	16,340	158,320	126,656	372,821	459,621
New York	110,364	9,153	15,184	25,981	43,750	75,230	60,184	200,236	259,170
Oklahoma.	34,156	....	....	....	....	34,156	27,325	111,215	111,215
Other states	18,366	100	300	1,100	4,200	17,166	13,733	83,715	88,215
Total.	816,478	81,455	93,914	60,791	106,237	674,232	539,387	1,889,190	2,089,341

Production by States, 1890–1901.—In Table 27 the amounts and value of the gypsum production, arranged by states, is given for the years 1890 to 1901 inclusive. During this period much of the growth in the gypsum industry took place in the Western States; while Texas and Oklahoma entered the list of producers. More recently the gypsum industry has renewed its activity in New York and Michigan.

TABLE 27.

PRODUCTION AND VALUE OF GYPSUM BY STATES, 1890–1901.

State.	1890.		1891.		1892.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Short tons.		Short tons.		Short tons.	
California........	4,249	$29,178	3,000	$36,360		
Colorado........	4,580	22,050	4,720	19,400	1,500	$1,500
Iowa............	20,900	47,350	31,385	58,095	12,000	28,500
Kansas..........	20,250	72,457	40,217	161,322	46,016	195,197
Michigan........	74,877	192,099	79,700	223,725	139,557	306,527
New York.......	32,903	73,093	30,135	58,571	32,394	61,100
Ohio............	12,748	87,533	9,123	36,586	13,275	49,521
South Dakota....	2,900	7,750	3,615	9,618		
Texas..........	....	....	....	....	1,926	8,640
Utah...........	....	....	3,000	15,000	2,600	16,300
Virginia.........	6,350	20,782	5,959	22,574	6,991	28,207
Wyoming........	3,238	22,231	1,992	6,200		
Total.........	182,995	574,523	212,846	647,451	256,259	695,492

State or Territory.	1893.		1894.		1895.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Short tons.		Short tons.		Short tons.	
California........	....	....	6	$30	5,158	$51,014
Colorado........	....	....	895	4,800	1,371	8,281
Indian Territory..	....	....	....	....	13,100	46,125
Iowa............	21,447	$55,538	17,906	44,700	25,700	36,600
Kansas..........	43,631	181,599	64,889	301,884	72,947	272,531
Michigan........	124,590	303,921	79,958	189,620	66,519	174,007
Montana.........	....	....	175	1,820		
New York.......	36,126	65,392	31,798	60,262	33,587	59,321
Ohio............	11,646	39,884	20,827	69,597	21,662	71,204
Oklahoma.......	....	....	1,300	7,500		
South Dakota....	5,150	12,550	4,295	16,050	6,400	20,600
Texas..........	4,011	13,372	6,925	27,300	10,750	36,511
Utah...........	....	....	1,920	12,225	2,134	11,484
Virginia.........	7,014	24,359	8,106	24,431	5,800	17,369
Wyoming........	....	....	312	1,500	375	2,400
Total.........	253,615	696,615	239,312	761,719	265,503	807,447

TABLE 27—(*Continued*).

PRODUCTION AND VALUE OF GYPSUM BY STATES, 1896–1901.

State or Territory.	1896.		1897.		1898.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Short tons.		Short tons.		Short tons.	
Arizona	....	....	30	$250	30	$700
Califorina	1,452	$11,738	351	2,774	3,800	24,977
Colorado	1,600	10,547	1,575	10,305	165	726
Indian Territory	8,000	24,000	10,734	40,050		
Iowa	18,631	34,020	29,430	64,900	24,733	45,819
Kansas	49,435	148,371	54,353	189,679	59,180	191,389
Michigan	67,634	146,424	94,874	193,576	93,181	204,310
Montana	385	1,940	425	2,300	1,123	7,272
New York	23,325	32,812	33,440	78,684	31,655	81,969
Ohio	22,634	63,583	18,592	50,856	21,303	61,884
Oklahoma	....	....	....	....	3,150	12,000
Oregon	....	....	....	....	150	450
South Dakota	6,115	20,000	8,350	19,240	2,740	9,200
Texas	16,022	48,070	24,454	65,651	34,215	58,130
Utah	2,866	13,600	2,700	13,500	2,610	10,080
Virginia	5,955	17,264	6,374	16,899	8,378	23,388
Wyoming	200	975	3,300	7,200	5,225	22,986
Total	224,254	573,344	288,982	755,864	291,638	755,280

State or Territory.	1899.		1900.		1901.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Short tons.		Short tons.		Short tons.	
Arizona	47	$1,200	35	$900		
California	2,950	14,950	3,280	10,088	3,550	$4,200
Colorado	871	3,904	967	5,300	13,291	64,772
Indian Territory	12,000	26,000	6,500	15,000		
Iowa	75,574	296,220	184,600	561,588	63,653	160,788
Kansas	85,046	247,690	48,636	150,257	69,390	213,260
Michigan	144,776	283,537	129,654	285,119	185,150	267,243
Montana	582	3,698	1,025	7,980		
New York	52,149	105,533	58,890	150,588	119,565	241,669
Nevada	....	....	1,000	4,805		
Ohio	27,205	73,520	39,034	119,946		
Oklahoma	11,526	36,600	18,437	60,380	15,930	66,031
Oregon	550	1,895	550	1,710		
South Dakota	550	4,000	2,050	13,800		
Texas	53,773	125,000	80,622	192,418	80,376	255,288
Utah	2,352	10,240	2,397	4,984		
Virginia	11,480	32,043	11,940	18,111	15,236	45,144
Wyoming	4,804	21,050	4,845	24,229	4,103	11,663
Other states	....	....	....	....	63,547	176,583
Total	486,235	1,287,080	594,462	1,627,203	633,791	1,506,641

Imports of Gypsum and Plaster.—Table 28 contains statistics relative to the amount of gypsum, etc., entering the different customs districts.

TABLE 28.

IMPORTS OF GYPSUM AND PLASTER.

IMPORTS OF CRUDE, GROUND, OR CALCINED (DUTIABLE) GYPSUM, BY CUSTOMS DISTRICTS, IN THE FISCAL YEARS ENDING JUNE 30, 1900, 1901, 1902, AND 1903.

Customs District into which Imported.	1903.		1902.		1901.		1900.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Long tons.		Long tons.		Long tons.		Long tons.	
Aroostook, Me.	128	$518	57	$148	415	$796	290	$448
Bangor, Me.	....	....	235	141	390	234	153	92
Bath, Me.	883	532	703	429	740	446	736	966
Passamaquoddy, Me.	11,394	11,131	8,395	7,628	8,232	7,942	9,503	10,530
Portland and Falmouth, Me.	....	....	....	....	180	135		
Boston and Charlestown, Mass.	9,120	19,420	5,760	11,546	5,921	11,118	6,450	11,925
Gloucester, Mass.	....	....	235	144	230	141		
Fairfield, Conn.	310	930	360	990	315	866	284	688
New Haven, Conn.	4,806	3,490	3,515	3,124	1,916	1,325	3,942	2,818
New York, N. Y.	169,232	184,935	157,699	167,444	117,989	138,565	121,728	150,074
Newark, N. J.	33,345	38,869	30,388	35,091	19,700	21,751	21,491	22,857
Perth Amboy, N. J.	4,910	3,795	6,218	3,733	2,780	1,661	4,230	2,538
Philadelphia, Pa.	42,849	52,362	33,343	39,471	23,900	25,233	21,216	25,828
Delaware.	....	....	1,630	960	1,387	816	2,325	1,401
Baltimore, Md.	2,925	2,487	3,987	3,040	5,635	3,381	3,822	2,834
Norfolk and Portsmouth, Va.	5,300	4,513	5,600	4,815	7,480	4,488	5,715	3,746
Alexandria, Va.	3,565	2,605	1,550	930	....	....	2,000	1,320
San Francisco, Cal.	....	....	....	....	2,236	9,700	1,014	4,500
Other districts.	11	98	20	22	1	72	32	333
Total.	288,778	325,685	259,695	279,656	199,447	228,670	204,850	242,898

In Table 29 the imports for the years 1900 to 1903 inclusive are given, classified according to the countries from which the products come. The amounts credited to Nova Scotia and New Brunswick are made up of crude gypsum. The imports from France and England, on the other hand, are almost entirely of the higher grades of finished plasters, as is shown by the high valuation per ton.

Comparison of Tables 29 and 30 shows that almost two-thirds of the entire gypsum production of Canada is sent into the United States as crude gypsum. This heavy importation has exercised an important influence in delaying the development of the New York and Virginia gypsum deposits, which are located near enough to tidewater to suffer from the competition.

TABLE 29.

IMPORTS OF CRUDE, GROUND, OR CALCINED (DUTIABLE) GYPSUM, BY COUNTRIES, IN THE FISCAL YEARS ENDING JUNE 30, 1900, 1901, 1902, AND 1903.

Country from which Imported.	1903.		1902.	
	Quantity.	Value.	Quantity.	Value.
	Long tons.		Long tons.	
France	57	$395	132	$1,902
United Kingdom	333	5,422	190	1,854
Nova Scotia and New Brunswick	288,366	319,497	259,353	275,877
Mexico				
Other countries	22	371	20	23
Total	288,778	325,685	259,695	279,656

Country from which Imported.	1901.		1900.	
	Quantity.	Value.	Quantity.	Value.
	Long tons.		Long tons.	
France	185	$1,311	342	$2,397
United Kingdom	93	987	59	836
Nova Scotia and New Brunswick	196,932	216,636	203,347	234,563
Mexico	2,236	9,700	1,014	4,500
Other countries	1	36	88	602
Total	199,447	228,670	204,850	242,898

World's Production of Gypsum.

The United States is the second country in the world in the production of gypsum, France being the first. Canada is third, Great Britain fourth, and Germany fifth. In the following table the production of the various countries since 1893 is set forth:

TABLE 30.

THE WORLD'S PRODUCTION OF GYPSUM, 1893–1903.

Year.	France.		United States.		Canada.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Short tons.		Short tons.		Short tons.	
1893......	....	....	253,615	$696,615	192,568	$196,150
1894......	1,693,831	$2,891,365	239,312	761,719	223,631	202,031
1895......	2,175,448	3,392,768	265,503	797,447	226,178	202,608
1896......	1,866,498	2,661,200	224,254	573,344	207,032	178,061
1897......	1,845,874	2,673,033	288,982	755,864	239,691	244,531
1898......	1,931,712	2,777,816	291,638	755,280	219,256	230,440
1899......	1,802,812	2,641,020	486,235	1,287,080	244,566	257,329
1900......	1,761,835	2,772,221	594,462	1,627,203	252,001	259,009
1901......	2,182,229	3,449,747	633,791	1,506,641	293,879	340,148
1902......	1,975,513	3,318,070	816,478	2,089,341	332,045	356,317
1903......	*	*	1,041,704	3,792,943	307,489	384,259

Year.	Great Britain.		German Empire.		Algeria.	
	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.
	Short tons.		Short tons.		Short tons.	
1893......	158,122	$287,940				
1894......	169,102	321,822	....	....	36,355	$114,900
1895......	196,037	348,400	23,994	$11,040	50,127	133,226
1896......	213,028	361,509	31,736	14,598	41,350	114,361
1897......	203,151	325,513	28,821	13,228	40,510	109,648
1898......	219,549	345,882	28,315	13,166	41,156	110,660
1899......	238,071	372,073	32,760	19,660	44,037	117,895
1900......	233,002	348,210	39,103	17,199	41,446	139,190
1901......	224,919	344,650	† 35,013	† 23,139	38,955	132,286
1902......	251,629	384,263	34,944	12,732	‡ 6,889	52,253
1903......	*	*	*	*	*	*

Year.	India.		Cyprus.	
	Quantity.	Value.	Quantity.	Value.
	Short tons.		Short tons.	
1893........................	....	....	2,357	$6,625
1894........................	3,548	$1,566	3,104	9,006
1895........................	7,511	2,987	2,093	5,252
1896........................	8,248	3,130	1,050	2,590
1897........................	9,025	3,333	4,167	8,162
1898........................	9,249	1,503	4,279	7,551
1899........................	7,216	768	4,402	8,866
1900........................	4,865	424		
1901........................	*	*	7,784	17,041
1902........................	*	*	7,874	17,443
1903........................	*	*	*	*

* Not yet available. † Includes Baden. ‡ Includes Tunis.

PART II. LIMES.

CHAPTER VI.

COMPOSITION, ORIGIN, AND GENERAL CHARACTERS OF LIMESTONES.

LIMESTONE is the raw material on which is based the manufacture of lime, and it is also the most important ingredient, in one form or another, in a Portland-cement mixture. Further, impure limestones of certain types are employed in the manufacture of hydraulic limes and natural cements. It will thus be seen that limestone plays a very important part in the manufacture of nearly all the cementing materials discussed in this volume, only the plasters (Chapters I–V) being manufactured without its use.

For this reason it has seemed desirable to discuss in the present chapter the origin, composition, varieties, and chemical and physical characters of limestone in general. This has been done in considerable detail. The present chapter will therefore serve as an introduction not only to the limes but to the hydraulic limes and the natural and Portland cements. More detailed statements concerning the special kinds of limestone required in the different industries will be found in the sections on those industries, particularly in Chapters XXIII–XXV of the section on Portland cement.

Origin of limestones.*—Limestones have been formed largely by the accumulation at the sea-bottom of the calcareous remains of such organisms as the foraminifera, corals, and mollusks. Many of the thick and extensive limestone deposits of the United States were probably deep-sea deposits formed in this way. Some of these limestones still show the fossils of which they were formed, but in others all trace of

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* For a more detailed discussion of this subject the reader will do well to consult Chapter VIII of Prof. J. F. Kemp's "Handbook of Rocks".


129°
125°
121°
117°
113°
109°
105°
101°
45°
41°
37°
33°
29°
25°
WASHINGTON
Seattle
Tacoma
Olympia
Spokane
Portland
Columbia River
Snake River
Lewiston
Salem
OREGON
Ashland
Klamath R.
IDAHO
Salmon R.
Boise
Snake Riv.
Pocatello
MONTANA
Great Falls
Missouri River
Helena
Butte
Bozeman
Billings
Yellowstone Riv.
Bighorn R.
Powder R.
Sheridan
YELLOWSTONE NATIONAL PARK
WYOMING
Laramie
Cheyenne
CANADA
NORTH DAKOTA
Bismarck
SOUTH DAKOTA
Pierre
Hot Springs
NEBRASKA
Platte Riv.
Ogden
Salt Lake City
Provo
Nephi
UTAH
Green R.
Grand R.
Colorado R.
COLORADO
Leadville
Denver
Pueblo
Durango
KANSAS
Arkansas R.
OKLAHOMA
Oklahoma
Cement
Quanah
NEVADA
Virginia
Carson
Eureka
CALIFORNIA
Sacramento R.
Sacramento
Stockton
Oakland
San Francisco
San Joaquin Riv.
Tulare Lake
Santa Barbara
Los Angeles
San Diego
ARIZONA
Colorado River
Prescott
Phoenix
Gila R.
Tucson
NEW MEXICO
Santa Fe
Albuquerque
Rio Grande
El Paso
TEXAS
Fort Worth
Colorado R.
Austin
Rio Grande
MEXICO
LOWER CALIFORNIA
GULF OF CALIFORNIA
PACIFIC OCEAN
L.L.POATES ENGR., N.Y.
117°
113°
109°
105°
101°
100
0
100

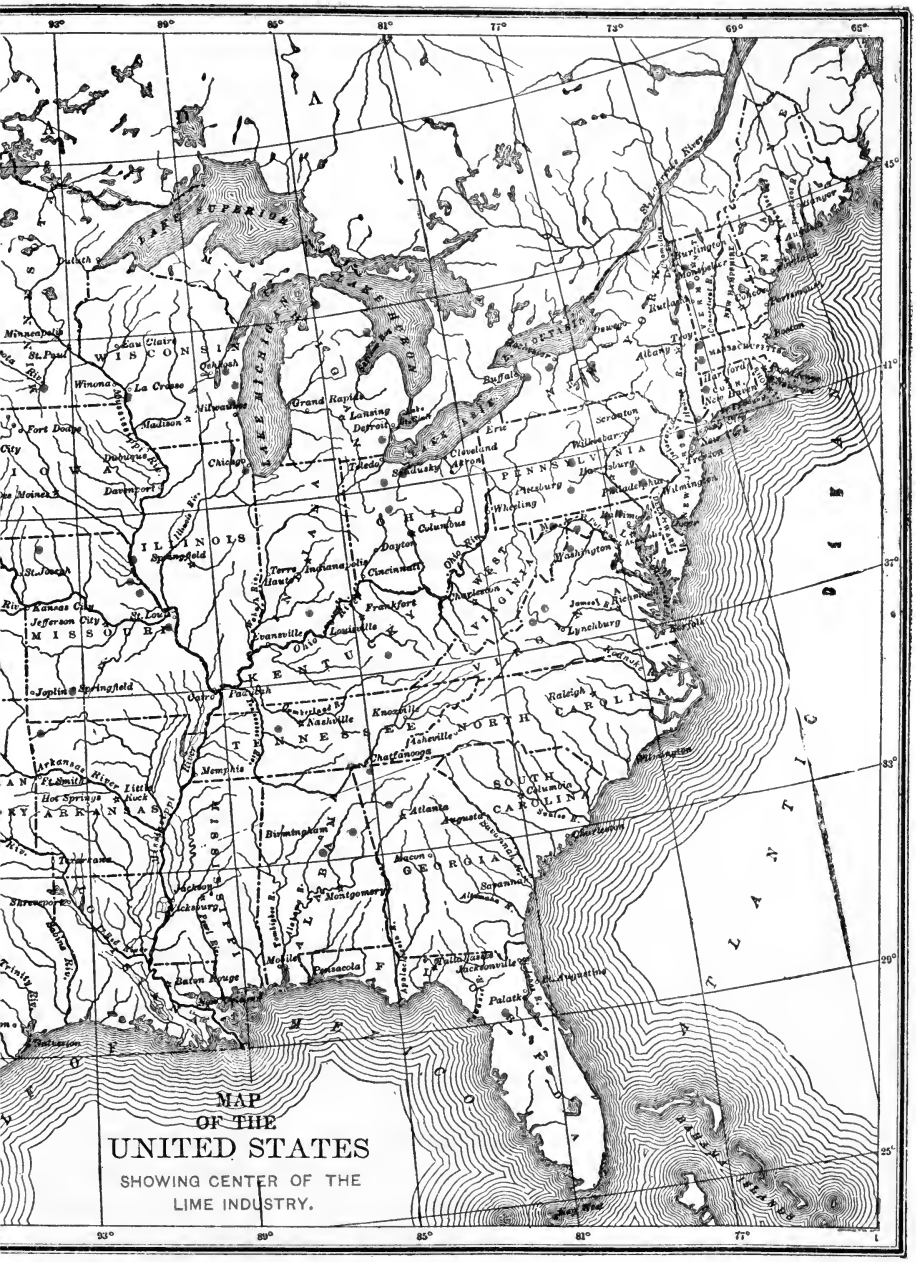

FIG. 19.

[*To face p. 88.*

organic origin has been destroyed by the fine grinding to which the shells and corals were subjected before their deposition at the sea-bottom. It is probable also that part of the calcium carbonate of these limestones was a purely chemical deposit from solution, cementing the shell fragments together.

A far less extensive class of limestones, though very important in the present connection, owe their origin to the indirect action of organisms. The "marls", so important to-day as Portland-cement materials, fall in this class. As the class is of limited extent, however, its method of origin may be dismissed here, but will be described later in the chapter on marls, pages 334–347.

Deposition from solution by purely chemical means has undoubtedly given rise to numerous important limestone deposits. When this deposition took place in caverns or in the open air it gave rise to onyx deposits and to the "travertine marls" of certain Ohio and other localities; when it took place in isolated portions of the sea through the evaporation of the sea-water it gave rise to the limestone beds which so frequently accompany deposits of salt and gypsum.

Varieties of limestone.—A number of terms are in general use for the different varieties of limestone, based upon differences of origin, texture, composition, etc. The more important of these terms will be briefly defined.

The *marbles* are limestones which, through the action of heat and pressure, have become more or less distinctly crystalline. The term *marl* as at present used in cement manufacture is applied to a loosely cemented mass of lime carbonate formed in lake basins as described in more detail in Chapter XXV. *Calcareous tufa* and *travertine* are more or less compact limestones deposited by spring or stream waters along their courses. *Oolitic* limestones, so called because of their resemblance to a mass of fish-roe, are made up of small rounded grains of lime carbonate. *Chalk* is a fine-grained limestone composed of finely comminuted shells, particularly those of the foraminifera. The presence of much silica gives rise to a *siliceous* or *cherty* limestone. If the silica present is in combination with alumina, the resulting limestone will be *clayey* or *argillaceous*.

Chemical composition of limestone.—A theoretically pure limestone is merely a massive form of the mineral calcite. Such an ideal limestone would therefore consist entirely of calcium carbonate or carbonate of lime, with the formula $CaCO_3[CaO+CO_2]$, corresponding to the composition calcium oxide (CaO) 56 per cent, carbon dioxide or carbonic acid (CO_2) 44 per cent.

As might be expected, the limestones we have to deal with in practice depart more or less widely from this theoretical composition. These departures from ideal purity may take place along either of two lines:

a. The presence of magnesia in place of part of the lime;

b. The presence of silica, iron, alumina, alkalies, or other impurities.

It seems advisable to discriminate between these two cases, even though a given sample of limestone may fall under both heads, and they will therefore be discussed separately.

The presence of magnesia in place of part of the lime.—The theoretically pure limestones are, as above noted, composed entirely of calcium carbonate and correspond to the chemical formula $CaCO_3$. Setting aside for the moment the question of the presence or absence of such impurities as iron, alumina, silica, etc., it may be said that lime is rarely the only base in a limestone. During or after the formation of the limestone a certain percentage of magnesia is usually introduced in place of part of the lime, thus giving a more or less magnesian limestone. In such magnesian limestones part of the calcium carbonate is replaced by magnesium carbonate ($MgCO_3$), the general formula for a magnesian limestone being, therefore,

$$x\mathrm{CaCO_3} + y\mathrm{MgCO_3}.$$

In this formula x may vary from 100 per cent to zero, while y will vary inversely from zero to 100 per cent. In the particular case of this replacement where the two carbonates are united in equal *molecular* proportions, the resultant rock is called dolomite. It has the formula $CaCO_3,MgCO_3$, corresponding to the composition calcium carbonate 54.35 per cent, magnesium carbonate 45.65 per cent. In the case where the calcium carbonate has been entirely replaced by magnesium carbonate, the resulting pure carbonate of magnesia is called magnesite, having the formula $MgCO_3$ and the composition magnesia (MgO) 47.6 per cent, carbon dioxide (CO_2) 52.4 per cent.

Rocks of this series may therefore vary in composition from pure calcite limestone at one end of the series to pure magnesite at the other. The term limestone has, however, been restricted in general use to that part of the series lying in composition between calcite and dolomite, while all those more uncommon phases carrying more magnesium carbonate than the 45.65 per cent of dolomite are usually described simply as more or less impure magnesites.

Though magnesia is often described as an "impurity" in limestone, this word, as can be seen from the preceding statements, hardly expresses the facts in the case. The magnesium carbonate present, whatever its amount, simply serves to replace an equivalent amount of calcium carbonate, and the resulting rock, whether little or much magnesia is present, is still a pure carbonate rock. With the impurities to be discussed in later paragraphs, however, this is not the case. Silica, alumina, iron, sulphur, alkalies, etc., when present are actual impurities, not merely chemical replacements of part of the calcium carbonate.

The presence of silica, alumina, iron, and other impurities.—If a number of limestone analyses be examined, it will be found that the principal impurities present are silica, alumina, iron oxide, sulphur, and alkalies.

Silica when present in a marble or crystalline limestone is usually combined with alumina, iron, lime, or magnesia, and occurs therefore in the form of a silicate mineral. In an ordinary limestone it is very often present as masses or nodules of chert or flint, or else combined with alumina as clayey matter. In the softer limestones, such as the chalks and marls, the silica may be present as grains of sand.

Alumina is commonly present combined with silica either as grains of a silicate mineral or as clayey matter.

Iron may be present as carbonate, as oxide, or in the sulphide form as the mineral pyrite.

Sulphur is commonly present in small percentages in one of two forms: as pyrite or iron disulphide (FeS_2) or as gypsum or lime sulphate ($CaSO_4+2H_2O$).

The alkalies soda and potash are frequently present in small quantity, probably in the form of carbonates.

Geologic and geographic distribution of limestones.—Limestones occur in every state and territory in the United States, though of course some states (Delaware, North Dakota, Louisiana, etc.) are so poorly supplied that they can never become important lime producers, while other states are almost entirely underlain by limestone strata. Geologically, the limestone utilized in various parts of the United States ranges entirely through the geological column, from the pre-Cambrian to the Pleistocene, inclusive.

Under such conditions of wide geographic and geologic distribution it is not practicable to give a summary of any value in the present volume. The list of references given in the following pages will enable the reader to ascertain the facts regarding the limestones of any given state in which he may be interested.

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Shells as sources of lime.*—Most molluscan shells consist essentially of lime carbonate, with commonly very small percentages (less than 1 per cent) of magnesium carbonate, and traces of alkalies, phosphoric acid, etc. The analyses given in Table 31 will serve to illustrate the composition of the shells of three common species of molluscs.

These analyses show that in ordinary practice an oyster-shell may be expected to contain, as its principal impurities, several per cent of organic matter and from a trace to 5 per cent of silica, iron oxide, and alumina. The amount of these last clayey impurities present will doubtless vary with the cleanness of the shell, as it is probable that they are in large part purely *external* impurities.

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* Brown, L. P., and Koiner, J. S. H. Analysis of oyster-shells and oyster-shell lime. American Chemical Journal, vol. 11, pp. 36–37. 1889.

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TABLE 31.

ANALYSES OF VARIOUS MOLLUSCAN SHELLS.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	3.30	1.49	n. d.	0.20	0.16	n. d.
Alumina (Al_2O_3)	0.08					
Iron oxide (Fe_2O_3)	0.17	0.04	n. d.	0.04		
Lime (CaO)	52.14	53.37	n. d.	52.86	54.55	54.38
Magnesia (MgO)	0.25					
Alkalies (K_2O,Na_2O)	0.35					
Sulphur trioxide (SO_3)	0.16	0.81	0.80	0.35	0.28	0.28
Phosphorus pentoxide (P_2O_5)	n. d.	0.11	n. d.	0.05	0.001	n. d.
Carbon dioxide (CO_2)	41.61	40.60	n. d.	41.02	42.82	n. d.
Water						
Organic matter	2.32	3.48	3.17	5.02	2.01	2.04

1. Oyster-shell. L. P. Brown and J. S. H. Koiner, analysts. Amer. Chemical Journal, vol. 11, pp. 36–37.
2–3. Oyster-shell. How, analyst. Amer. Journal of Science, 2d series, vol. 41, p. 380.
4. Mussel-shell. " " " " " " " " " " "
5–6 Periwinkle-shell. " " " " " " " " " " p. 379–381.

At various points where the oyster-canning industry is largely developed oyster-shells are burned into lime. An important lime-burning industry is, for example, based upon the use of waste oyster-shells at Baltimore, Md. In the case of the lime whose analysis is given below the shells had been charged, mixed with small anthracite, into a cylindrical kiln, and the resulting lime consequently shows the presence of a considerable amount of coal-ash. By burning the shells in kilns with separate furnaces this can be avoided, giving a much improved product.

The following analyses were made * by L. P. Brown and J. S. H. Koiner on the oyster-shell used in lime-burning at Baltimore, Md., and the resulting lime.

TABLE 32.

ANALYSES OF OYSTER-SHELLS AND OYSTER-SHELL LIME.

	Shell.	Lime.
Silica (SiO_2)	3.30	6.29
Alumina (Al_2O_3)	0.08	0.42
Iron oxide (Fe_2O_3)	0.17	0.33
Lime (CaO)	52.14	85.49
Magnesia (MgO)	0.25	0.31
Alkalies (K_2O,Na_2O)	0.35	0.80
Sulphur trioxide (SO_3)	0.16	0.66
Carbon dioxide (CO_2)	41.61	0.70
Water	.....	3.97
Organic matter	2.32	

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* American Chemical Journal, vol. 11, p. 37, 1889.

CHAPTER VII.

LIME-BURNING.

BEFORE taking up the discussion of manufacturing methods it will be of value to consider briefly the chemical principles upon which these methods are based and the classes of products which result.

The burning of a pure non-magnesian limestone.—An absolutely pure limestone, free from both magnesia and other impurities, corresponds in composition to calcium carbonate ($CaCO_3$). If a pure limestone be heated to 800° C. or over, this carbonate is dissociated, the carbon dioxide (CO_2) being driven off as a gas, while the calcium oxide (CaO) is left behind as a white solid, known as quicklime or caustic lime. This decarbonation may be expressed in a formula as follows:

$$\text{Limestone } (CaCO_3) + \text{heat} = CaO \text{(lime)} + CO_2 \text{ (carbon dioxide)}.$$

As the original lime carbonate consisted of 56 parts by weight of CaO to 44 parts of CO_2, the formula may be given a commercial quantitative value, as below:

$$\text{100 lbs. limestone} + \text{heat} = \text{56 lbs. quicklime} + \text{44 lbs. carbon dioxide}.$$

In the process of burning from limestone to quicklime, the material has therefore lost 44 per cent in weight. It has also decreased in bulk, but in a much smaller ratio, the decrease varying from 12 to 20 per cent. Pure limestone has a specific gravity of 2.715, while the true specific gravity of pure quicklime is 3.09 to 3.15, though much less in lumps.

The dissociation of limestone on heating begins at a temperature of about 750° C., but is usually not complete until 900° C. or thereabouts is reached. As the expulsion of the carbon dioxide is hindered by the presence of the gas itself dissociation is accomplished more rapidly if either (*a*) the carbon-dioxide gas, as fast as it is formed, is removed from the kiln by a pump, or (*b*) a jet of steam or water is introduced, the effect being to form a mixture of steam and carbon dioxide, which exerts less pressure than would the pure gas alone. In practice the pumping method is rarely used, but the injection of water or steam is quite a common practice.

The burning of a magnesian limestone.—If the limestone, though otherwise pure, contains magnesium carbonate, the effects produced by burning will vary somewhat from those discussed above. Suppose, for example, that a limestone consisting of 60 per cent lime carbonate +40 per cent magnesium carbonate be burned until dissociated. The original limestone consisted of

$$60 \text{ lbs. } CaCO_3(=CaO+CO_2)+40 \text{ lbs. } MgCO_3(MgO+CO_2).$$

While lime carbonate is made up of 56 per cent CaO plus 44 per cent CO_2, magnesium carbonate contains 47.6 per cent MgO plus 52.4 per cent CO_2. The bulk composition of the original limestone may, therefore, be expressed quantitatively as follows:

60 lbs. lime carbonate =	33.60 lbs.	CaO
	26.40 "	CO_2
40 " magnesium carbonate =	19.04 "	MgO
	20.96 "	CO_2

The original rock, therefore, carries in 100 lbs. 33.60 lbs. of lime (CaO), 19.04 lbs. of magnesia (MgO), and 47.36 lbs. of carbon dioxide (CO_2).

If a rock of this composition be burned, the carbon dioxide will be driven off, as in the case of a pure limestone, but the solid mass remaining will consist partly of lime (CaO) and partly of magnesia (MgO). In addition to this difference, a difference in loss of weight is to be noted. In discussing the burning of a pure non-magnesian limestone it was stated that the driving off of the carbon dioxide meant the loss of 44 per cent in weight. In the case of the particular magnesian limestone here discussed it can be seen that the expulsion of the carbon dioxide is equivalent to a loss of 47.36 per cent in weight.

Dissociation, in the case of a magnesian limestone, appears to be effected at a somewhat lower temperature * than when a non-magnesian limestone is burned, but no accurate data on this point are available.

Classification of limes.—For commercial purposes limes carrying less than 5 per cent of magnesia can be marketed as pure or high-calcium limes; but those containing over 5 per cent differ so markedly in their properties that it is necessary to class them separately. The groups are, therefore, as follows:

GROUP A. High-calcium limes: Limes containing less than 5 per cent of magnesia. The limes of this group differ among themselves according to the amount of silica, alumina, iron, etc., contained. A lime carrying less than 5 per cent of such impurities is a "fat" or "rich" lime, as distinguished from the more impure "lean" or "poor" limes.

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* Probably about 600°–700° C.

Group B. Magnesian limes: Limes containing over 5 per cent (*usually* 30 per cent or over) of magnesia. These limes are all slower slaking and cooler than the high-calcium limes of the preceding group, and they appear to make a stronger mortar. They are, however, less plastic or "smooth", and in consequence are disliked by workmen. As commercially produced, they usually carry over 30 per cent of magnesia.

Methods and Costs of Lime-burning.

Compared with the complicated processes employed in the manufacture of Portland cement, lime-making is a very simple industry, the only distinctive operation requiring attention being the burning of the limestone. In the present section the types of lime-kilns employed at various localities will be considered, detailed descriptions of several of the more important styles being given. A few brief notes on the utilization of a hitherto practically unused by-product (carbon dioxide) will then be given, after which the costs of lime-manufacture will be considered.

Heat requirements in lime-burning.—In burning limestone to lim- heat is required for three purposes:

(*a*) Evaporating any water contained in the limestone.
(*b*) Heating the limestone to its dissociation temperature.
(*c*) Driving off carbon dioxide from the lime (and magnesium) carbonate.

The water in the limestone, however, aids in the dissociation, so that the first heat requirement may be neglected here. Heating the limestone from the air temperature (say 60° F.) to its point of dissociation (about 1300° F. for non-magnesian limestones), assuming that within this range the specific heat of limestone is 0.22, would require, for one ton of limestone $2000 \times 0.22 \times (1300-60) = 545{,}600$ B.T.U. For a magnesian limestone, which loses its carbon dioxide at a lower temperature, this amount would be considerably reduced.

The heat used in the actual dissociation is known quite accurately. One pound of lime carbonate ($CaCO_3$) will require 784 B.T.U. for its dissociation, while one pound of magnesium carbonate would require only 381 B.T.U. Using, then, these data in connection with those quoted in the preceding paragraph, the following tabulated statement can be made concerning the total heat requirements in burning limestones of different composition. In actual practice, of course, the fuel consumption is always far in excess of these theoretical requirements.

TABLE 33.

HEAT AND FUEL THEORETICALLY REQUIRED IN BURNING ONE TON OF LIMESTONE.

	Composition of Limestone.		
	100% $CaCO_3$.	80% $CaCO_3$, 20% $MgCO_3$.	50% $CaCO_3$, 50% $MgCO_3$.
Heat required for heating to dissociation-point.	545,600 B.T.U.	457,600 B.T.U.	369,600 B.T.U.
Heat required for actual dissociation.	1,568,000 "	1,406,800 "	1,165,000 "
Total heat requirements. . . .	2,113,600 B.T.U.	1,864,400 B.T.U.	1,534,600 B.T.U.
Coal theoretically required (14,000 B.T.U. per lb.):			
Intermittent kilns.	151 lbs.	133 lbs.	110 lbs.
Continuous kilns.	112 lbs.	101 lbs.	76 lbs.

The above results are to be regarded only as approximations to the truth, because the chemical data on which the calculations are based are not accurately determined, but the figures suffice to show the great economy in fuel consumption which comes from the use of highly magnesian limestone.

Types of lime-kilns.—The types of kilns employed in lime-burning may be grouped as follows:

Intermittent kilns }
Continuous kilns } . . . . (1)
Vertical kiln, mixed feed. . . { limestone and fuel fed in alternate layers } . . . . . . (2)
Vertical kiln, separate feed. . . limestone and fuel not in contact (3)
Ring or chamber kiln . . . . (4)

(1) *Intermittent kilns* are those in which each burning of a charge constitutes a separate operation. The kiln is charged, burned, cooled, and the charge is drawn; then the kiln is again charged, and so on. The disadvantages of this intermittent mode of operation are obvious; and kilns of this type are consequently employed only where there is a slight or very irregular demand for the product. Old kilns of this kind can still be seen in farming regions, where charges of lime are burned as the neighborhood demand requires.

These primitive kilns were [*] "rudely constructed of stone, and were located on the side of a hill, so that the top was easily accessible

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[*] Blatchley, S. W. 29th Ann. Rep. Indiana Dept. Geology, pp. 225–227, 1904

for charging the kiln with stone and the bottom for supplying fuel and drawing out the lime. In charging, the largest pieces of limestone were first selected and formed into a rough dome-like arch with large open joints springing from the bottom of the kiln to a height of five or six feet. Above this arch the kiln was filled from the top with fragments of limestone, the larger pieces being used in the lower layers, these being topped off with fragments of smaller size. A wood fire was then started under the dome, the heat being raised gradually to the required degree in order to prevent the sudden expansion and consequent rupture of the stones forming the dome. Should this happen, a downfall of the entire overlying mass would take place, putting out the fire and causing the total loss of the contents of the kiln. After a bright heat was once reached throughout the mass of stone, it was maintained for three or four days to the end of the burning. This was indicated by a large shrinkage in volume of the contents of the kiln, the choking up of the spaces between the fragments, and the ease with which an iron rod could be forced down from the top. The fire was then allowed to die out and the lime was gradually removed from the bottom. It was in this manner that all the lime used in Indiana for many years was burned, and in some localities these temporary intermittent kilns are still in operation. The process of burning is simple and cheap, the only expense being for blasting the stone and preparing the fuel. Possibly but one or two kilns were necessary to supply a neighborhood for a year. These were operated for a week or two when required and remained idle for the remainder of the year.

"As the population increased, the demand for lime became greater, and in many places permanent kilns lined with fire-brick were erected. These were the old-fashioned stone 'pot-kilns' of a quarter century ago. On the inside they were usually circular in horizontal section, tapering slightly, by a curve both up and down, from the circle of largest diameter, which was from 4 to 6 feet above the bottom. A kiln 10 to 11 feet in greatest diameter was 25 to 28 feet high, 5 to 6 feet in diameter at the top and 7 to 8 feet at the bottom. There was an arched opening on one side at the bottom 5 or 6 feet high, through which the wood was introduced and the burnt lime removed. A horizontal grating on which the fire was built was usually placed 1 or 2 feet above the bottom.

"In all these intermittent kilns there was an enormous loss of heat at each burning, for the quantity of fuel necessary to raise the contents of the kiln and the thick stone and brick walls to the necessary degree of heat had to be repeated each time the kiln was charged. Moreover, the stone nearest the dome arch in the kiln was liable to become injured by overburning before the top portions of the charge where toroughly calcined."

(2) *Vertical kilns with mixed feed.*—In kilns of this type the limestone and fuel are charged into the kiln in alternate layers. As the burning progresses burned lime is drawn from the bottom of the kiln, while fresh layers of limestone and fuel are added at the top.

The advantages of *mixed-feed* kilns, as compared with the separate feed-kilns described below, are (*a*) that they are cheaper to construct, (*b*) that they are somewhat more economical of fuel, and (*c*) that they give for the same size of kiln a larger output in the same time. These advantages are partly counterbalanced by the disadvantages to which they are subject, these being (*a*) that the burned lime is discolored to some extent by its contact with the fuel, (*b*) that the ashes of the fuel cannot readily be separated from the burned lime, thereby lowering the quality of the product, and (*c*) that a part of the fuel ashes may clinker on the outside of the lumps of lime, preventing even and satisfactory burning.

To sum up the advantages and disadvantages: the "mixed-feed" kiln is cheaper both in first cost and in operating expenses; its product is good enough for most ordinary purposes, but is not as evenly burned or as white as is the product of a "separate-feed" kiln.

At a small Pennsylvania lime-plant three vertical mixed-feed kilns are in use. Each of these kilns takes about 24 tons of stone per day, requiring the services of six quarrymen to keep the three kilns supplied. Bituminous slack is used for fuel, the consumption being 26 lbs. slack per bushel (75 lbs.) of lime, equivalent to a fuel consumption of 34.7 per cent on the weight of lime produced. This ratio if correct is enormous compared to natural- or even Portland-cement plants, and points to unusually inefficient management. As a general rule, a vertical mixed-feed kiln may be expected to produce lime with a fuel consumption of from 15 to 25 per cent of the weight of clean product. The cause of this apparently high consumption is that so much of the product is usually unfit for use.

The Aalborg or Schöfer kiln, one of the best types of stationary kilns for cement practice, has been employed in a somewhat modified form for burning lime and hydraulic lime. The lime-kiln of this type is shown in Fig. 21. The limestone is fed in at the charging door *B*, while the fuel is charged through the chutes *ff*. The mass of limestone in the preheating chamber *D* is dried, heated, and partly decarbonated before it enters the burning-zone, when the decarbonation is complete.

The cooling-chamber *C* reduces the temperature of the burned lime and incidentally heats the air which passes through it to supply combustion. These features make the Aalborg kiln very economical in fuel consumption. Each kiln will turn out 15 to 20 tons per day, and

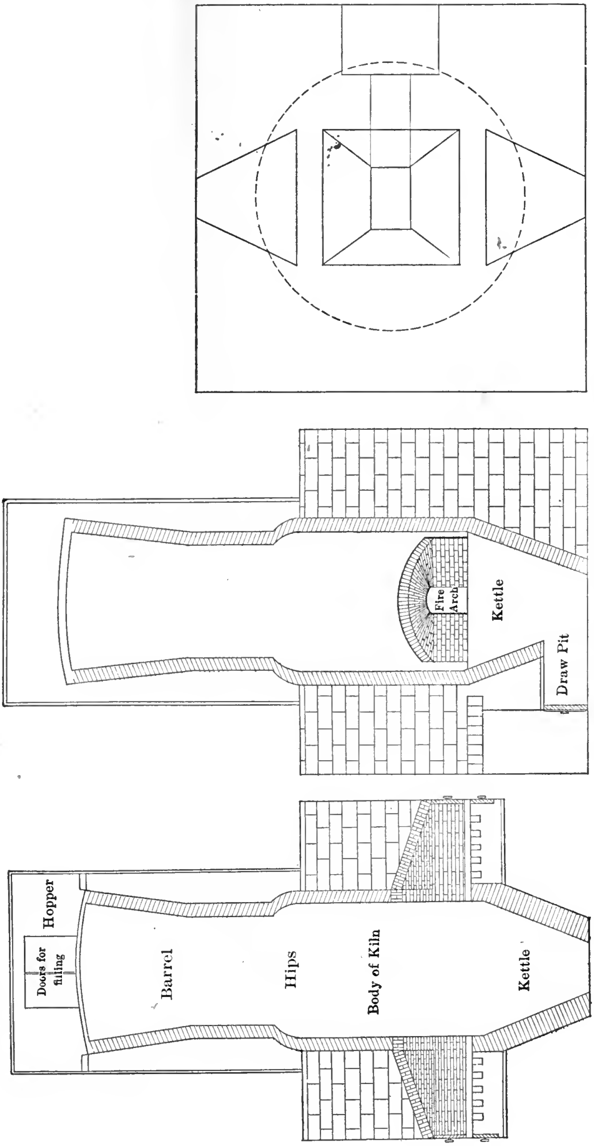

FIG. 20.—Plan and sections of lime-kiln.

will use 220 to 260 pounds of coal per ton of quicklime burned, equivalent to a fuel consumption of 10 to 12 per cent on the weight of the product, which is very close to the theoretical minimum.

(3) *Vertical kilns with separate feed.*—Kilns of this type, which are now used at most of the larger lime-burning plants, are equipped with separate fireplaces to carry the fuel, distinct from the body of the kiln.

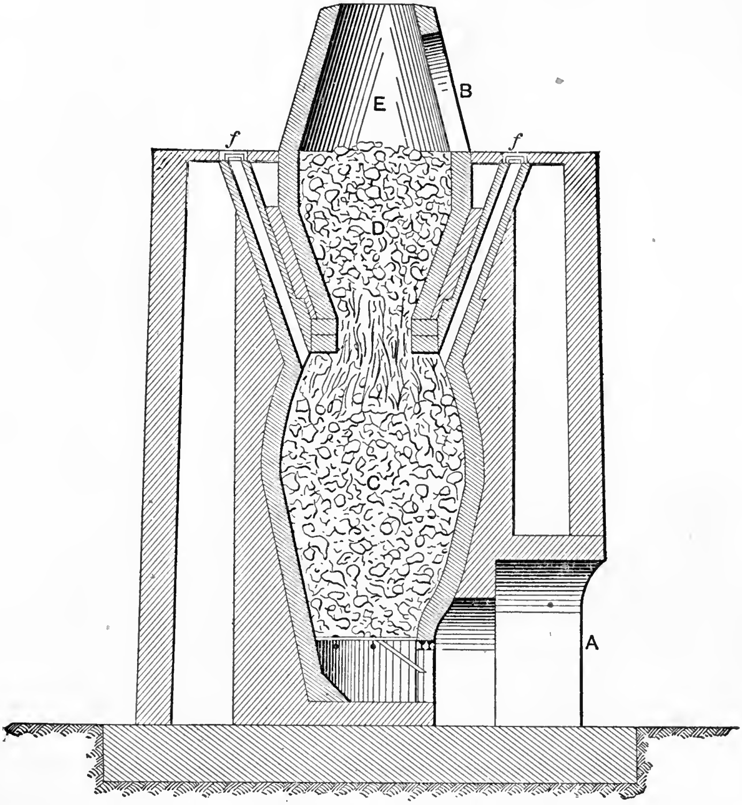

Fig. 21.—Aalborg kiln for lime-burning.

These fireplaces may be set either in the wall of the kiln, the usual position when a stone-walled kiln is used, or outside of the kiln-shell. The kiln body proper contains the charge of limestone, while the fuel is fed and burned in these fireplaces or furnaces. The limestone, therefore, does not come into direct contact with the fuel, but only with the hot fuel gases. Other things being equal, kilns of this type could not show quite as high a fuel efficiency as kilns in which the limestone and fuel are charged together in alternate layers. The product, however, is of a much higher grade, for it is not discolored by contact with the fuel, and it contains no fragments of unburned fuel or fuel ashes and clinkers. With average care in feeding and burning, it is probable that at least 90 per cent of the product from a kiln of this type will be a well-burned clean white lime, as compared with the 75 or 80 per cent obtainable from mixed-feed kilns. As the fuel-burning apparatus is entirely distinct from the body of the kiln, the firing can be kept under better control, so that the percentage of underburned and overburned material in the product should be materially decreased.

Kilns of this type are commonly 35 to 50 feet in height and 5 to 8 feet in inside diameter, with either two or four fireplaces or "furnaces".

The Keystone kiln, described in detail below, may be taken as fairly representative of this type of lime-kiln.

The Keystone kiln is built on Broomell's patent by the Broomell, Schmidt & Steacy Company, of York, Pa. Its construction can be clearly seen from Fig. 22, which shows the kiln with a portion of the shell cut away to exhibit the interior, and with the side wall of the furnace removed to show its construction. The kiln from top to floor is a heavy steel shell lined with fire-brick. The base of the kiln below the firing platform is made from very heavy steel plates, reinforced on the inside by numerous stiffening-ribs. The furnaces are carried on steel platforms which extend a sufficient distance in front of the firing-doors to give a convenient working space. In addition to being supported at the inner ends by attachment to the shell of the kiln the steel beams which floor the platforms rest at their outer ends on steel columns.

In operating this kiln the flame from the coal (or wood) burned in each furnace is directed through two large openings in the kiln shell and lining directly against the limestone which fills the kiln. These openings, as well as the kiln shell and the furnaces, are lined with fire-brick.

As the lime passes the burning-zone it falls into a "cooling-cone" made of steel plates. This is an inverted hollow frustum of a cone suspended from a heavy cast-iron plate, which in turn is supported by gusset plates riveted to the base of the kiln. The cooling-cone varies from 6 to 6½ feet in diameter at top, according to the size of the kiln, and is 7 feet high. The burned and partly cooled lime is drawn from the cone by means of shears or draw-gates at its bottom. These gates are operated by hand-wheels which project outside of the kiln base, thus removing the operator from the dust and heat of the lime. The

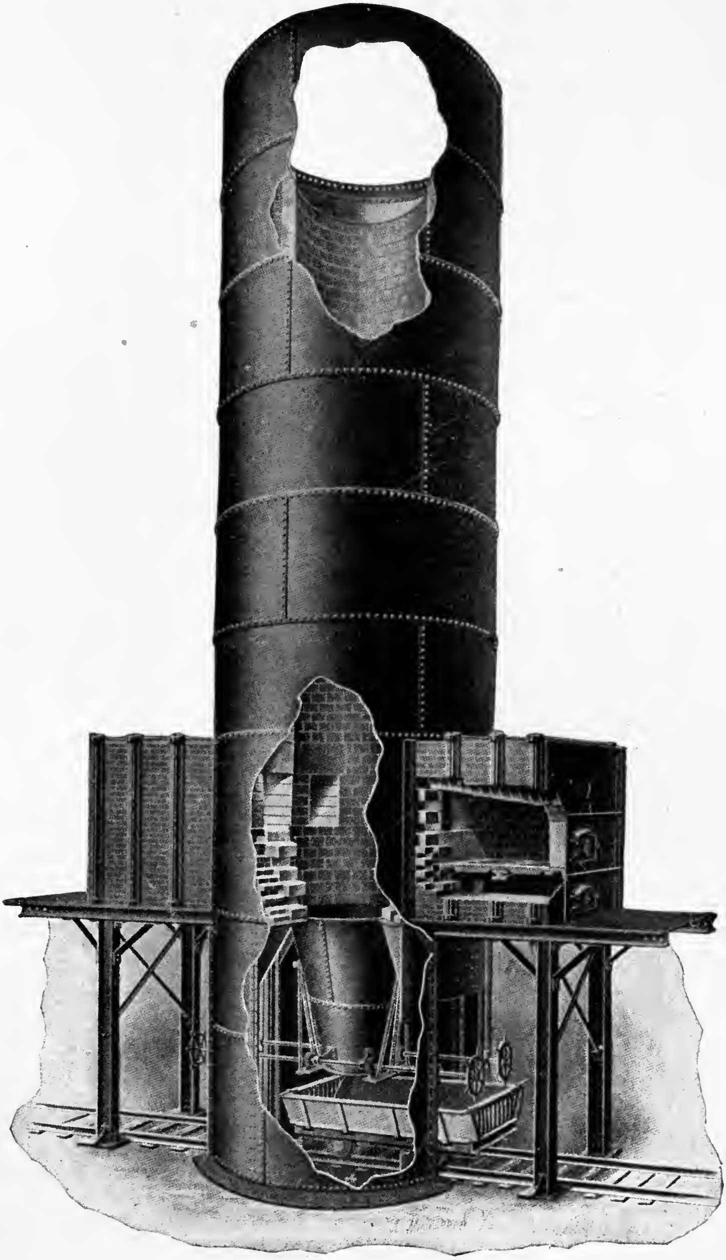

FIG. 22.—Keystone lime-kiln.

lime can be discharged into a car run in under the cooling-cone or on the floor. The heated air which ordinarily would accumulate around the cooling-cone is discharged into the ash-pit under the grates, which adds considerably to the efficiency of the furnace. Arrangement can also be made for placing a steam-jet in the hot-air passage so as to provide forced draft if desired.

TABLE 34.

DIMENSIONS OF KEYSTONE LIME-KILNS.

	No. 1.	No. 2.	No. 3.
Outside diameter of shell	10 ft.	11½ ft.	12 ft.
Inside diameter of lining	5 "	6 "	6½ "
Total height	38 "	43 "	48 "
Output per day, in bushels of 70 lbs.	200–250	250–300	300–350

Many patents have been taken out to cover improvements in various details of the ordinary lime-kiln. One of these patented devices is shown in Fig. 23, where boilers are inserted in the kiln arches so as to utilize the waste heat of the kiln. The boilers, in turn, are used to develop the power needed for running drills, hoists, and other machinery in the quarry and mill.

(4) *Ring or chamber kilns.*—Chamber kilns of the Hoffman type, though never used in America, are in somewhat extensive use in Europe for both lime and Portland-cement burning. They are described briefly on pages in connection with the burning of Portland cement. When used for burning lime in Europe, a fuel consumption of 400 to 450 lbs. coal per ton (2000 lbs.) of burned lime is attained in common practice, while lower consumption can be expected under favorable conditions. The Hoffman kiln is, of course, a great improvement in both economy and quality of product on the old style of vertical kiln, but it is doubtful if it gives better results than the modern kilns now in use in the more important American lime-plants.

Gen. Q. A. Gillmore stated * in 1871 that a Hoffman kiln used for lime-burning at Llandulas, Wales, produced about 80 tons of lime per day at the following detailed cost:

Cost of quarrying stone, including tools	$0.31¼
Charging kiln	0.10½
Drawing kiln	0.07¼
Wages of burners	0.07¼
Fuel at $1.75 per ton.	0.37½
Managing expenses, etc.	0.31¼
Cost of lime per ton	$1.25

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* Gillmore, Q. A. A practical treatise on Coignet-Béton and other artificial stone. pp. 71–72, 1871.

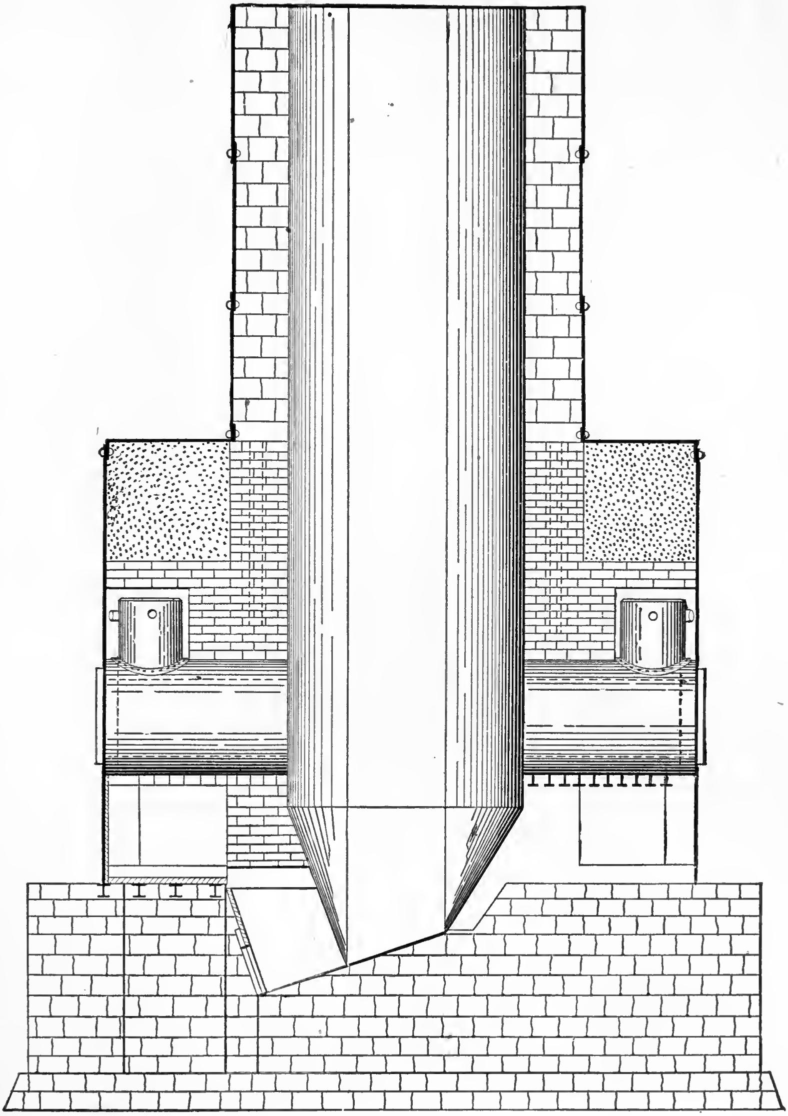

FIG. 23.—O'Connell lime-kiln.

He further estimated that at the current prices (1871) of labor and fuel in the United States, lime could be manufactured in a Hoffman kiln at about $2 per ton, the following details of cost being given:

Cost of quarry and plant	$20,000
Annual yield of kiln, tons	20,000
	Per Ton Lime.
Interest on investment	$0.07
Quarrying stone	0.65
Charging kiln	0.20
Drawing kiln	0.15
Wages of burners	0.15
Fuel	0.43
Contingent expenses, 20 per cent	0.33
	$1.98

Utilization of carbonic-acid gas from lime-kilns.—During the burning of limestone to lime an enormous amount of carbonic-acid gas (carbon dioxide, CO_2) is driven off and usually wasted. The extent of this waste may be appreciated when it is recalled that 100 lbs. of pure limestone would give on calcination 56 lbs. of quicklime and 44 lbs. of carbon dioxide. To put the matter in another way, for every ton (2000 lbs.) of lime made 1571 lbs. of carbon dioxide are thrown into the atmosphere. During the year 1903, therefore, over one and a half million tons of carbon dioxide were produced—and wasted—from the lime-works of the United States. Few attempts have been made by lime-manufacturers to utilize this valuable by-product, though the manufacture of carbonic acid, as an independent industry, has become of great importance.

Mr. Henry A. Mather states * that carbon dioxide from lime-kilns "helps make profitable a well-rounded operation in Oldbury, England, the only surviving chemical works using the Leblanc soda process. The salt cake is burned in furnaces, the soda bleached out, the chlorine recovered, and the sludge of partially decomposed carbonaceous matter containing a large percentage of sulphite of lime is treated in closed agitators with carbonic-acid gas obtained from burning lime rock in a closed kiln. The hydrogen disulphide driven off in this operation of precipitating the carbonate of lime is burned in a Klaus kiln, air in proper proportions enters with the gas, and flowers of sulphur is the final product of this part of the operation". A further utilization of by-products at this plant occurs when the carbonate of lime so pre-

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* Engineering and Mining Journal, March 29, 1902.

cipitated is mixed with clay and burned into Portland cement. An editorial note appended to Mr. Mather's article states that the Hargreaves-Bird alkali-works at Middlewich, England, also use waste carbon-dioxide gas from lime-kilns.

Cost of lime-manufacture.—With the exception of a comparatively few large and well-managed lime-plants, lime-manufacture in the United States is not so steadily and economically handled as to give much basis for generalizations concerning costs. The result is that the data obtainable are rarely definite enough to be of much service. The following is probably as fair a statement of the case as can be made.

The principal items to be considered in estimating the cost of lime-manufacture are:

(1) Interest on cost of plant and quarry.
(2) Cost of quarrying limestone.
(3) Cost of fuel for burning.
(4) Labor costs, exclusive of quarry.

The interest on cost of plant and quarry will vary greatly according to the steadiness with which the plant is operated. This is, of course, true with regard to the same item in the cement industry, but lime-plants are in general subject to greater fluctuations in output. The estimates given below of interest charges per ton of lime are therefore given a very wide limit, but it is believed to be impracticable to place them more definitely.

The cost of quarrying is also variable, but within narrower limits. In large, carefully managed quarries located near the kilns, and with stone and stripping so arranged as to admit of cheap extraction, the cost of quarrying the limestone and transporting it to the kiln may fall as low as 25 cents per ton. This cost is attained in Portland-cement quarries in the Lehigh district of Pennsylvania, and in a number of natural-cement and lime quarries elsewhere. On pages 378, 379 will be found further details as to cost of quarrying, one of the examples being of the costs at a quarry worked both for Portland cement and for lime. With average skill in locating and managing the quarry, it is probable that the cost of quarrying need never rise above 40 or 45 cents per ton of rock. Allowing for waste and loss by under or over-burning, 2 tons of limestone will be required to make 1 ton of lime. This would give as the probable limits of cost of quarrying 50 to 90 cents per ton of burned lime.

Wood is still used for fuel at many lime-kilns, in which case the cost of fuel may be merely nominal or may be very high. When coal is used for fuel in a modern kiln, the coal consumption per ton of burned lime may vary from 300 to 500 lbs. These limits have been assumed in the estimate below, while the cost of coal has been taken as varying from $2 to $3 per ton. These prices are fairly representative for most of the lime-plants of the country.

Labor costs are estimated with a rather liberal maximum limit.

The final results of these calculations are shown below.

TOTAL COST OF LIME-MANUFACTURE PER TON.

Interest on cost of plant and quarry.......	$0.05	to	$0.20
Taxes, minor supplies, etc................	0.10	"	0.25
Cost of quarrying two tons of limestone....	0.50	"	0.90
Cost of fuel for burning..................	0.30	"	0.75
Cost of labor, exclusive of quarrymen......	0.25	"	0.80
Total cost per ton of burned lime, in bulk (2000 lbs.)................	$1.20	"	$2.90

This corresponds to costs of 4.2 to 10.15 cents per bushel of 70 lbs. The minimum estimate represents what might be attained by a good modern plant, run steadily and under exceptionally favorable conditions as regards quarrying, fuel, and labor. The maximum estimate could easily be exceeded by the small or unsteadily operated plants. The average cost throughout the entire country is probably in the neighborhood of 6 to 8 cents per bushel.

General estimates of costs of lime-manufacture by the use of Hoffman kilns will be found on pages 106 and 108.

Actual costs of lime-manfuacture in 1900.—In connection with the above estimates of cost it is of interest to compare certain statistics collected by the Census Bureau in 1900 and published in vol. 7, Reports Twelfth Census, pp. 274–277. The tables on the pages cited give total costs of various elements in lime- and cement-manufacture in all the states during 1900. As the figures for lime, natural cement, and Portland cement are tabulated together, most of the tables are of little value for our present purpose. In the ten states considered below, however, no natural- or Portland-cement plants were in operation during 1900, so that the statistics for these states must necessarily apply only to the lime industry. The data relating to these ten states have accordingly been slightly rearranged and are shown in the following table.

As the total quantities of lime produced are not stated, it is impossible to reduce the total costs given in the table to costs per ton or bushel of product. A simple calculation, however, enables us to reduce them to percentages of the total cost, so that the relative importance of the various elements making up this total can be readily

TABLE 35.

COST OF LIME-MANUFACTURE DURING 1900 IN TEN STATES.

State	Arkansas.	Connecticut.	Iowa.	Maine.	Massachusetts.
Number of plants	5	11	28	20	11
Total capital	$53,894	$250,392	$663,830	$1,942,007	$115,639
In land	11,598	71,720	89,100	485,338	20,100
In buildings	10,865	65,550	159,325	681,515	28,700
In machinery	9,396	26,915	261,785	143,225	16,800
In cash, etc.	22,125	86,207	153,620	631,929	50,039
Salaried officials	6	12	38	34	3
Total salaries	$3,075	$9,640	$26,588	$26,296	$2,640
Laborers	78	171	302	582	130
Total wages	$15,600	$71,938	$145,382	$248,371	$69,823
Rent, taxes, etc.	$6,409	$21,932	$68,488	$97,878	$7,630
Limestone, cost of	$21,097	$86,759	$134,300	$347,344	$67,826
Fuel, cost of.	8,150	59,005	41,564	196,991	54,257
Mill supplies, etc.	....	963	4,345	33,101	40
Freight	250	2,025	1,305	68,803	310
Value of product	$70,900	$286,640	$543,267	$1,226,972	$261,477

State	Missouri.	Rhode Island.	Tennessee.	Vermont.	West Virginia.
Number of plants	31	3	12	13	7
Total capital	$797,926	$26,150	$158,886	$176,825	$256,860
In land	201,852	8,000	39,300	51,900	142,500
In buildings	232,119	4,000	27,680	31,450	28,500
In machinery	107,675	2,500	20,751	19,925	9,160
In cash, etc.	256,280	11,650	71,155	73,550	76,700
Salaried officials	48	1	4	2	15
Total salaries	$46,350	$360	$2,350	$1,400	$9,260
Laborers	583	40	167	182	128
Total wages	$206,837	$16,230	$50,665	$57,257	$47,200
Rent, taxes, etc.	$40,045	$9,752	$2,492	$9,367	$1,400
Limestone, cost of	$100,174	$8,314	$16,614	$36,804	$6,175
Fuel, cost of.	109,974	8,700	20,305	45,112	24,840
Mill supplies, etc.	2,960	125	1,110	7,636	30
Freight	20,802	....	1,857	6,000	3,800
Value of product	$600,432	$48,089	$166,423	$207,524	$109,393

noted. In Table 36, below, this has accordingly been done. The interest charges have been taken at 6 per cent of the total capital, and no specific allowance has been made for depreciation or repairs, as these items for the year in question must appear under one of the other headings. The value of the product has also been calculated, in percentages of the total cost.

TABLE 36.

ELEMENTS OF COST OF LIME-MANUFACTURE, EXPRESSED IN PERCENTAGES OF TOTAL COST.

	Ark.	Conn.	Iowa.	Maine.	Mass.	Mo.	R. I.	Tenn.	Vt.	W. Va.	Average.
Interest.	5.6	5.6	8.6	10.3	3.3	8.5	3.4	9.1	6.1	14.2	7.47
Salaries.	5.3	3.6	5.9	2.3	1.3	8.1	0.8	2.3	0.8	8.6	3.90
Wages.	26.9	26.8	31.4	21.9	33.3	35.9	36.1	48.3	32.9	43.7	33.72
Taxes, etc. . .	11.1	8.2	14.8	8.6	3.7	6.9	21.7	2.4	5.3	1.3	8.40
Limestone. . .	36.5	32.5	29.1	30.6	32.4	17.4	18.4	15.8	21.1	5.7	23.95
Fuel.	14.1	22.1	9.0	17.3	25.9	19.1	19.3	19.3	25.9	23.0	19.50
Supplies.	0.0	0.4	0.9	2.9	0.0	0.5	0.3	1.1	4.4	0.0	1.05
Freight.	0.5	0.8	0.3	6.1	0.1	3.6	. . . . .	1.7	3.5	3.5	2.01
Total cost.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.00
Value of product. . .	122.7	107.2	117.6	108.1	124.8	104.0	106.7	158.6	1.191	1.012	117.00

Statistics of the Lime Industry.—The importance of the lime industry might easily be underrated were it not that very accurate statistics on the subject are available. These show that for some years past the value of the annual production of lime in the United States has been in the neighborhood of $10,000,000.

In Table 37 is given the value of the lime production in the United States for the years 1902 and 1903 by States and Territories. These figures are taken from the volumes on " Mineral Resources of the United States", issued annually by the U. S. Geological Survey, and may be accepted as being a close approximation to the actual production.

In considering these figures it should not be forgotten that they include all the lime burned in the country for whatever purpose the product may be employed. It is probable that of the $10,105,190, at which the total lime production for 1903 is valued, about $7,000,000 would represent the value of the lime used for structural purposes—i.e., as mortar, plaster, and in the lime-sand brick industry. Much of the remainder of the product is used in various chemical industries, notably in the manufacture of alkali, gas, paper, sugar, leather, etc., etc., while a large proportion is used as a fertilizer. The proportion of lime used for structural purposes to that used for chemical and agricultural purposes will vary in the different states, and cannot be accurately determined. Pennsylvania, Ohio, New York, and Michigan are probably the largest producers of lime for non-structural uses.

TABLE 37.

LIME PRODUCTION OF THE UNITED STATES.

	1902.	1903.
Alabama	$235,568	$217,326
Arizona	....	1,260
Arkansas	82,853	89,337
California	395,995	396,750
Colorado	46,866	53,637
Connecticut	203,899	152,568
Florida	37,933	44,137
Georgia	71,724	62,902
Idaho	13,049	18,200
Illinois	485,644	481,439
Indiana	312,189	314,206
Indian Territory	....	800
Iowa	114,146	98,630
Kansas	7,358	14,480
Kentucky	15,893	50,988
Maine	742,132	791,690
Maryland	332,251	321,713
Massachusetts	324,480	262,815
Michigan	306,232	351,209
Minnesota	77,214	66,719
Missouri	515,780	646,048
Montana	8,775	21,100
Nebraska	550	1,624
Nevada	$2,800	$2,400
New Jersey	123,478	120,816
New Mexico	....	1,000
New York	604,759	698,674
North Carolina	2,090	600
Ohio	1,144,495	1,007,316
Oklahoma	25	4,000
Oregon	20,133	13,684
Pennsylvania	1,446,333	1,451,040
Rhode Island South Carolina	70,124	38,432 43,830
South Dakota	21,300	13,051
Tennessee	235,615	198,663
Texas	82,500	74,118
Utah	99,463	493,290
Vermont	219,306	180,769
Virginia	241,984	338,126
Washington	186,070	226,948
West Virginia	190,368	166,332
Wisconsin	549,357	559,494
Wyoming	2,250	12,033
Total	$9,573,011	$10,105,190

An examination of Table 37 will show that during the year 1903 lime was burned in 44 states and territories. Only six political divisions failed to appear as lime producers—Delaware, Louisiana, Mississippi, New Hampshire, North Dakota, and the District of Columbia. Of these six the District of Columbia is known to contain no limestone, while in Delaware the limestone outcrops are few and unimportant. The only limestone occurring in North Dakota is too impure for most purposes, being in fact a natural-cement rock. Louisiana contains a few small areas of limestone. In New Hampshire, however, limestones are much commoner; while in Mississippi several important limestone areas occur but are not at present utilized.

The rank of the various states in regard to value of lime produced was, for the year 1903, as follows:

(1) Pennsylvania, (2) Ohio, (3) Maine, (4) New York, (5) Missouri, (6) Wisconsin, (7) Utah, (8) Illinois, (9) California, (10) Michigan,

(11) Virginia, (12) Maryland, (13) Indiana, (14) Massachusetts, (15) Washington, (16) Alabama, (17) Tennessee, (18) Vermont, (19) West Virginia, (20) Connecticut, (21) New Jersey, (22) Iowa, (23) Arkansas, (24) Texas, (25) Minnesota, (26) Georgia, (27) Colorado, (28) Kentucky, (29) Florida, (30) South Carolina, (31) Rhode Island, (32) Montana, (33) Idaho, (34) Kansas, (35) Oregon, (36) South Dakota, (37) Wyoming, (38) Oklahoma, (39) Nevada, (40) Nebraska, (41) Arizona, (42) New Mexico, (43) Indian Territory, (44) North Carolina.

It may be stated that the production assigned to Utah for 1903 ($493,290) is incredibly large, and that the state would in reality probably rank about twenty-fifth instead of ninth if more detailed statistics could be obtained. The rank assigned to Kansas, on the other hand, seems remarkably low.

CHAPTER VIII.

COMPOSITION AND PROPERTIES OF LIME.

The lime (or "quicklime") resulting from the burning of a pure limestone is a white solid, with a specific gravity of 3.09 to 3.15. As packed, it will weigh about 60 lbs. per cu. ft., or 70–75 lbs. per bushel. When made from a limestone rock, the lime should be in lumps, the occurrence of powder or dust proving that the lime has been exposed to the air so much since burning that air-slaking has begun. When the lime has been made from shells, marl, highly crystalline marbles, soft chalk, or shelly limestones, however, it will often come from the kilns in small fragments, which in this case is no sign of deterioration.

If the raw material is impure, containing much clayey matter or iron oxide, the resulting lime will not be white, but will vary from yellowish to gray or brown in color, according to the amount and kind of impurities present. It will also, in general, slake much slower than would a purer product.

High-calcium vs. magnesian limes.—The relative merits of these two classes have been frequently discussed in text-books and technical journals, and are still subjects of controversy. The facts of the case, however, seem to be simple enough and may be summarized as follows:

High-calcium limes slake rapidly on the addition of water, and evolve much heat during slaking They also expand greatly, giving a large bulk of slaked lime. Magnesian limes slake very slowly, and evolve very little heat during the process. Their expansion is also less; so that, taking equal weights, they give less bulk of slaked lime.

Owing to the slowness and coolness with which the magnesian limes slake, there is some danger that the average mortar-mixer * will not give them sufficient time to slake thoroughly. Owing to the fact that they make less bulk of slaked product than do the high-calcium limes, the average contractor or builder thinks that they are too expensive. But, on the other hand, they are very much stronger in long-time tests

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* A human, not mechanical, mortar-mixer is here spoken of.

than the high-calcium limes, and will therefore carry much more sand. This fact is brought out, for one instance, by the tests given on p. 122.

Composition of commercial high-calcium limes.—The non-magnesian or high-calcium limes as marketed will rarely carry less than 90 per cent of lime oxide (CaO), while they commonly carry over 95 per cent. The remaining 5 or 10 per cent is made up of magnesia MgO), silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and a little carbon dioxide and water. In the following table a number of analyses of representative high-calcium limes are given.

TABLE 38.

ANALYSES OF HIGH-CALCIUM LIMES (U. S.).

No.	Silica (SiO_2).	Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon Dioxide (CO_2) and Water.
1*	0.18	0.26	98.44	0.98	0.32
2	0.37	0.21	97.11	0.56	n. d.
3	1.69	n. d.	96.11	0.11	n. d.
4	1.01	1.30	97.72	n. d.	n. d.
5	0.81	0.75	98.30	n. d.	n. d.
6	1.14	0.17	95.66	0.76	3.00
7	0.36	0.15	98.13	0.42	0.80
8	0.81	0.47	96.63	0.88	0.12
9	1.96	0.94	95.60	0.14	1.36
10	3.42	1.21	94.26	0.32	0.79
11	0.79	0.26	97.48	1.40	n. d.
12	3.2	1.4	94.0	1.40	n. d.
13	1.88	2.03	91.93	3.06	n. d.
14	1.70		96.46	0.64	1.20
15	0.80		97.60	0.36	1.24
16	0.23	1.29	97.64	0.80	n. d.
17	1.06	0.58	95.50	tr.	2.08
18	1.93	0.27	94.07	0.79	3.04
19	3.20	0.80	94.80	1.21	n. d.
20	0.43	0.36	97.82	0.12	n. d.
21	0.56	0.22	97.89	1.05	n. d.
22	0.25	0.15	97.46	0.73	1.41
23	0.15	0.16	97.82	0.85	1.02
24	tr.	tr.	98.47	1.12	0.45
25	0.10	0.12	99.29	0.46	n. d.
26	0.02	tr.	98.84	0.12	1.02
27	0.38	0.65	98.26	0.30	n. d.
28	0.14	tr.	99.23	0.60	n. d.
29	0.27	0.19	98.14	1.40	n. d.
30	0.18	0.26	98.44	0.98	0.32
31	0.30	0.42	98.24	0.56	0.54
32	2.22	n. d.	96.93	0.85	n. d.
33	0.42	0.33	97.71	1.15	0.32
34	0.78	0.52	98.40	0.10	n. d.
35	1.38	0.62	97.80	0.18	n. d.

* For references see next page.

Limes of this type slake rapidly when water is added and develop much heat during slaking. They also expand notably, so that the resulting paste (slaked lime) will be much more bulky than the original lime.

Lean or poor limes.—A lime containing over 5 per cent of such impurities as silica, alumina, and iron oxide will usually be dark in color, comparatively slow slaking, and difficult to trowel in working. Such limes are known as " lean " or " poor " limes. In a few cases the impurities are so evenly and finely distributed throughout the original limestone that on burning the limestone a certain amount of combination takes place between the lime (CaO) and the impurities. This gives slightly hydraulic properties to the product. Ordinarily, however, no such chemical combination takes place on burning, and the impurities simply serve to depreciate the quality of the lime produced.

The following analyses (Table 39) are of lean limes produced at various localities in the United States.

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28. W. B. Fonda, St. Albans, Vt. F. C. Robinson, analyst. 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 456.
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TABLE 39.

ANALYSES OF LEAN LIMES.

Silica (SiO_2)	2.43	3.24	3.50	1.62	10.20	5.50	6.29
Alumina (Al_2O_3)	6.80	4.26	3.92	2.62	3.60	1.99	0.42
Iron oxide (Fe_2O_3)							0.33
Lime (CaO)	81.38	81.92	83.20	82.40	81.33	84.40	85.49
Magnesia (MgO)	1.34	n. d.	n. d.	n. d.	1.17	1.80	0.31

The last of the above analyses is of a lime made by burning oystershells in a mixed-feed kiln. In this case the impurities shown in the lime are largely the result of coal-ash taken up by the lime during manufacture. (See pp. 94, 95.)

Composition of commercial magnesian limes.—In discussing the classification of limes, pp. 97, 98, it was stated that limes carrying over 5 per cent of magnesia were to be grouped commercially as magnesian limes. In the present place this statement will bear discussing in somewhat more detail.

In theory a limestone can carry anywhere from 0 to 45.65 per cent of magnesium carbonate ($MgCO_3$). In the first case it would have the composition of the mineral calcite ($=CaCO_3$), in the second that of the mineral dolomite ($CaCO_3+MgCO_3$), while the intermediate stages falling between these two limits (0 and 45.65 per cent $MgCO_3$) would be known simply as magnesian limestones. A further theoretical conclusion is that such intermediate stages would occur approximately as commonly as the extreme stages.

In practice, however, we find that this last theoretical deduction does not hold. If a large series of limestone analyses be compared, it will be found that by far the great majority of them are of the two extremes of the series. That is to say, actual limestones are either *very* low in magnesia or *very* high in it. This condition causes the product made by burning limestone to fall usually in one of the two following classes:

A. High-calcium limes: magnesia less than 5 per cent.

B. High-magnesium limes: magnesia over 30 per cent.

Intermediate limes are of course burned, but they are comparatively rare. Analyses 10, 11, 12, and 13 of Table 40 are of such intermediate types, carrying respectively 7.41, 7.52, 13.42, and 6.08 per cent of magnesia.

The composition of the typical magnesian limes is well shown by analyses 1–9, inclusive, of Table 40.

Lime-slaking.—The subject of lime-slaking has always been a matter of importance in connection with the ordinary use of lime in making

TABLE 40.

ANALYSES OF MAGNESIAN LIMES (U. S.).

<table>
<tr><th>Number.</th><th>Silica (SiO_2).</th><th>Alumina (Al_2O_3) and Iron Oxide (Fe_2O_3).</th><th>Lime (CaO).</th><th>Magnesia (MgO).</th><th>Carbon Dioxide (CO_2), Water, etc.</th></tr>
<tr><td>1</td><td colspan="2">0.42</td><td>56.57</td><td>42.56</td><td>0.10</td></tr>
<tr><td>2</td><td>7.25</td><td>1.24</td><td>55.74</td><td>34.07</td><td>1.62</td></tr>
<tr><td>3</td><td colspan="2">0.88</td><td>56.81</td><td>37.98</td><td>2.84</td></tr>
<tr><td>4</td><td colspan="2">0.80</td><td>58.00</td><td>38.45</td><td>2.80</td></tr>
<tr><td>5</td><td>1.61</td><td>0.17</td><td>57.44</td><td>40.36</td><td>0.41</td></tr>
<tr><td>6</td><td>2.95</td><td>1.35</td><td>58.33</td><td>37.37</td><td>n. d.</td></tr>
<tr><td>7</td><td>0.46</td><td>1.10</td><td>55.49</td><td>42.31</td><td>0.64</td></tr>
<tr><td>8</td><td>0.07</td><td>2.62</td><td>63.03</td><td>34.15</td><td>0.13</td></tr>
<tr><td>9</td><td>0.35</td><td>0.49</td><td>59.20</td><td>38.38</td><td>1.80</td></tr>
<tr><td>10</td><td>1.09</td><td>1.74</td><td>81.83</td><td>13.42</td><td>1.92</td></tr>
<tr><td>11</td><td>n. d.</td><td>0.38</td><td>91.72</td><td>7.52</td><td>n. d.</td></tr>
<tr><td>12</td><td>1.78</td><td>0.75</td><td>90.07</td><td>7.41</td><td>n. d.</td></tr>
<tr><td>13</td><td>0.15</td><td>1.70</td><td>90.20</td><td>6.08</td><td>0.30</td></tr>
</table>

1. Canaan Lime Co., Canaan, Conn. J. S. Adam, analyst. 20th Ann. Rep. U. S. Geol. Sur. pt. 6, p. 370.
2. Ladd Lime Works, Bartow, Ga. N. P. Pratt, analyst. 20th Ann. Rep. U. S. Geol. Sur., pt. 6, p. 375.
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mortar for structural work. During the past few years, however, it has assumed a far greater importance as being an essential part of the manufacture of " hydrated lime " and " lime-sand bricks ". The theoretical aspects of the slaking of lime will be discussed in the section below, while the discussion of the actual methods of slaking will be found on pp. 120, 121 and in the two succeeding chapters (IX and X), which deal with the manufacture and properties of hydrated lime and of lime-sand brick respectively.

If water be poured upon a lump of pure quicklime, lime hydrate will be formed, while considerable heat will be evolved, the lime will expand notably in bulk, and the lump will fall into powder. The chemical combination that takes place during this operation is represented in a formula by

$$CaO + H_2O = CaO_2H_2.$$

(Lime) + (Water) = (Lime hydrate)

With absolutely pure lime the amount of water that must be added in order to change all of the quicklime into lime hydrate will equal 32.1 per cent, by weight, of the quicklime. The resulting lime hydrate will therefore consist of 75.7 per cent lime (oxide) and 24.3 per cent water. Lime hydrate is a fine white powder, with a specific gravity of 2.078.

Effect of impurities present.—The above percentages would only hold true in case the burned lumps consisted entirely of quicklime (CaO). Actually we know that this theoretical purity is never attainable on a commercial scale. The original limestone always contains silica, alumina, iron oxide, etc., in quantities more or less large. The limestone is, moreover, never perfectly burned, so that some portions of unburned lime carbonate will always be present in the product.

The presence of these impurities, including silica, alumina, iron oxide, and fragments of unburned lime carbonate, operates to reduce the amount of water theoretically required for perfect slaking of the lime. For example, a perfectly pure lump of quicklime 100 lbs. in weight would require 32.1 lbs. of water for complete slaking. If the lump contained 10 per cent of impurities, however, it would require only 28.9 lbs. of water.

Expansion of volume.—The impurities also serve to reduce the expansion of volume which the lime would otherwise show. A pure lime, if slaked by adding the entire quantity of water at once, may increase 3½ times in volume; if slaked gradually, only part of the water being added at a time, it will increase much less; while if allowed to air-slake its increase in volume will be only about 1.7 times its original volume. An impure lime, as above noted, will show less expansion, the difference being in direct ratio to the percentage of impurities.

The rapidity and intensity of the slaking will also be less with an impure than with a pure lime, and the amount of heat evolved during slaking will be decreased.

Effect of the presence of magnesia.—If the lime contain any considerable percentage of magnesia, slaking will take place more slowly and with less evolution of heat, while the expansion of volume will be less. In consequence of the slowness of the slaking more care is necessary with magnesian than with high-calcium limes in order to insure that the product has been thoroughly slaked.

Methods of slaking lime in ordinary practice.—When lime is used for making ordinary building-mortar, the common practice is to add much more than the amount of water theoretically required. The result is not only to slake the lime but to convert the slaked lime into a thin or thick paste, according to the amount of water used. When ordinary laborers are slaking lime it is evident that this method possesses the great advantage of being on the safe side. It is possible that the addition of the surplus water weakens the mortar somewhat, but on the other hand it insures thorough slaking, or would insure it if even reasonably good care were taken during the operation. The trouble, however, has been that lime-slaking is not regarded as an art, but as a disagreeable necessity, and it is usually carried on by laborers who are not even supposed to know anything about the subject.

The result of these conditions is that the slaked lime used in mortar rarely even approaches its theoretical efficiency. Either so much water has been added that the strength of the product is impaired or else the water-supply or mixing has been insufficient and the product is not thoroughly slaked.

A realization of these facts has caused the introduction of ready-slaked lime, prepared carefully at the lime-plants. This product is discussed in the following chapter under the head of "Hydrated lime". In its preparation particular care is given to insuring that the product shall be thoroughly slaked, and that this slaking shall be done with as little water as possible. Several distinct methods of slaking have accordingly been devised and are in use at different lime-hydrating plants.

In ordinary practice, where quicklime is slaked on the work, only one general method is followed, though books on construction invariably list and describe several other methods. The process as actually carried out is to form, on a plank floor or on a bed of sand, a circular wall of sand. The lime is shoveled into the ring thus formed and water is turned on from a hose until the laborer considers the amount sufficient. The lime commences to slake more or less quickly according to its composition, and when the process is completed it is covered over with a thin layer of sand until required for mortar.

Use of lime mortars.—Lime is never used alone as a binding material, for it shrinks greatly on drying and hardening, and this shrinkage would produce cracks if nothing were added to the mortar to counteract it. In practice sand is always added to lime mortars, the proportions for ordinary use being from two to four parts sand to one part lime paste.

The hardening of lime mortars is a simple process, though occasionally statements of opposite tenor may be found in print. It may be accepted as proven that lime mortars harden by simple recarbonation, the lime gradually absorbing carbon dioxide from the atmosphere and becoming, in fact, artificial limestones. As this absorption can take place only on the surface of the masonry, the lime mortar in the interior of a wall never becomes properly hardened. In this process the sand of the mortar takes no active part. It is merely an inert material, added solely in order to prevent shrinkage and consequent cracking. In this connection the reader may be referred to a discussion on pages 132, 133 of the theory of lime-sand brick manufacture.

Strength of lime mortars.—Few recent determinations have been made on this point, as lime is steadily decreasing in importance as an engineering material.

The following tests, made by Mr. George S. Mills of Toledo, Ohio, have been recently published.* They are directly related to the point under discussion and furnish strong evidence of the superiority of the highly magnesian limes.

The limes tested were made by burning limestones of the following composition:

Constituents.	Magnesian.	High Calcium.
Silica (SiO_2)	0.45	n. d.
Alumina (Al_2O_3)	0.28	n. d.
Iron oxide (Fe_2O_3)		
Lime carbonate ($CaCO_3$)	54.20	86.22
Magnesium carbonate ($MgCO_3$)	45.06	9.27

The limes resulting from burning the above limestones were slaked, mixed with sand in the proportion of one part slaked lime to two parts sand by weight, and made into briquettes, which were tested at various ages, with the results shown below. The figures given are in pounds per square inch and each value represents the average of the tests of from four to six briquettes.

TABLE 41.

TENSILE STRENGTH OF MAGNESIAN AND HIGH-CALCIUM LIMES. (MILLS.)

Age.	High-calcium Lime.	Magnesian Lime.
4 weeks	$30\frac{2}{3}$	
8 "	$36\frac{2}{5}$	$28\frac{5}{6}$
3 months	$39\frac{1}{4}$	$37\frac{1}{6}$
4 "	39	51
6 "	$50\frac{5}{6}$	83
1 year	$44\frac{3}{5}$	$92\frac{5}{6}$

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* Rhines, G. V. Tensile strength of high-calcium and magnesium limes Municipal Engineering, vol. 28, pp. 4–7. Jan. 1905.

In 1895 a series of experiments * on the strength of lime mortars was made by L. C. Sabin in connection with work on the Saulte Ste. Marie canal. The results of these tests are given in Table 42, below.

In preparing the lime 120 lbs. of water was added to 40 lbs. quicklime, and after a few days the excess water was poured off and the paste passed through a 10-mesh sieve to remove lumps. In the original tables the percentages of lime and water in the various lime pastes are given. In the following table, however, this has been omitted, and the ratio given is that between the sand and the dry quicklime.

TABLE 42.

STRENGTH OF LIME MORTARS. (SABIN.)

Composition, Parts by Weight.		Kind of Sand.	Age.	No. of Tests.	Tensile Strength, Pounds per Square Inch.		
Lime.	Sand.				Maximum.	Minimum.	Average.
1	3	Standard...............	28 days	5	58	26	46
1	6	“	“	5	69	50	62
1	8.8	“	“	5	62	37	47
1	8.8	Natural, passing 10-mesh.	“	5	68	60	63
1	11.8	Standard...............	“	5	54	30	39
1	17.7	“	“	5	32	8	20
1	3	Crushed limestone.	29 days	5	50	24	37
1	6	Screened, 20–40 mesh. ...	“	5	66	38	51
1	8.8	“ “ “	“	5	76	55	64
1	8.8	Natural, passing 10-mesh.	“	5	66	54	59
1	11.8	Screened, 20–40 mesh....	“	5	68	52	56
1	17.7	“ “ “	“	5	48	40	43
1	3	Standard...............	3 months	5	52	42	47
1	3	Crushed limestone.	“	5	64	20	51
1	6	Standard...............	“	5	59	40	47
1	6	Screened, 20–40 mesh....	“	5	63	43	56
1	8.8	Standard...............	“	5	60	46	52
1	8.8	Screened, 20–40 mesh....	“	5	78	67	71
1	8.8	Natural, passing 10-mesh.	“	5	87	58	67
1	8.8	“ “ “	“	5	74	56	66
1	11.8	Standard...............	“	4	63	39	47
1	11.8	Screened, 20–40 mesh....	......	5	64	46	55
1	17.7	Standard...............	......	4	40	34	36
1	17.7	Screened, 20–40 mesh....	......	5	41	38	39

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* Report of the Chief of Engineers, U. S. A., for 1896, pt. 5, p. 2839. 1896.

CHAPTER IX.

HYDRATED LIME: ITS PREPARATION AND PROPERTIES.

IN the preceding chapter it has been stated that quicklime (CaO) combines with about one-third of its own weight of water to form slaked or hydrated lime (CaH_2O_2). It has been further stated that lime-slaking when done on construction work by ordinary laborers is very inefficiently accomplished. This has always been realized, but it has only been within the past few years that any extensive effort has been made to provide a more satisfactory article for the contractor or builder.

Under the names of " new-process lime ", " hydrated lime ", " limoid ", etc., a large number of lime-plants have within recent years placed a ready-slaked lime on the market. When this product is carefully prepared, it does away with all the trouble, waste, and unsatisfactory results entailed by the old method of slaking lump lime on the work. It seems probable, therefore, that increased knowledge of its valuable properties and increased care in its preparation will result in a great extension of its production and a corresponding decrease in the amount of lime marketed in the unhydrated form.

Preparation of hydrated lime.—In preparing hydrated lime on a commercial scale three stages of manufacture are necessary. These are:

(1) The lump quicklime must be ground to a fairly uniform small size.

(2) The powder or grains resulting must be thoroughly mixed with sufficient water.

(3) The slaked lime must finally be sieved or otherwise brought to a uniform fine powder.

Numberless patents have been issued to cover one or more of the points above named, but the general stages are the same in all. These will now be taken up separately and briefly discussed.

Grinding the quicklime.—Though grinding is practiced at most lime hydrate plants, great variation exists in the extent to which it is carried. In some plants the quicklime is simply crushed to, say, ½ inch or 1 inch size, while in others the grinding is much finer. At a recently installed plant using the Dodge process, the quicklime passes first through a small crusher, which reduces it to about $\frac{1}{2}$ inch. The product is then fed to Sturtevant rock-emery mills, which reduce it so that about 80 per cent will pass a 50-mesh sieve.

A new rotary fine crusher, devised by the Sturtevant Mill Company, has also been used for crushing hydrated lime to $\frac{1}{2}$ inch or so. The following details regarding this crusher are taken from a recent catalogue.

TABLE 43.

SIZES, CAPACITY, ETC., OF STURTEVANT CRUSHER.

Number.	Hopper Opening, Inches.	Approximate Capacity, Tons per Hour.	Approximate Horsepower.	Speed, Revolutions.	Pulley Diameter, Face.	Approximate Weight, Pounds.	Length.	Width.	Height.
1	13×18	2 to 6	6 to 10	300	24× 8	4000	6′ 6″	3′ 2″	5′ 8″
2	20×30	8 to 15	15 to 20	250	32×12	7500	8′ 2″	4′ 2″	6′ 10″

Mixing with water.—The next step is the actual slaking, and here considerable differences of practice appear, depending partly on what particular patented process is followed. The mixing is commonly carried on in a pan with agitators, similar to a familiar form of concrete mixer, or in a horizontal cylinder. All the lime may be added

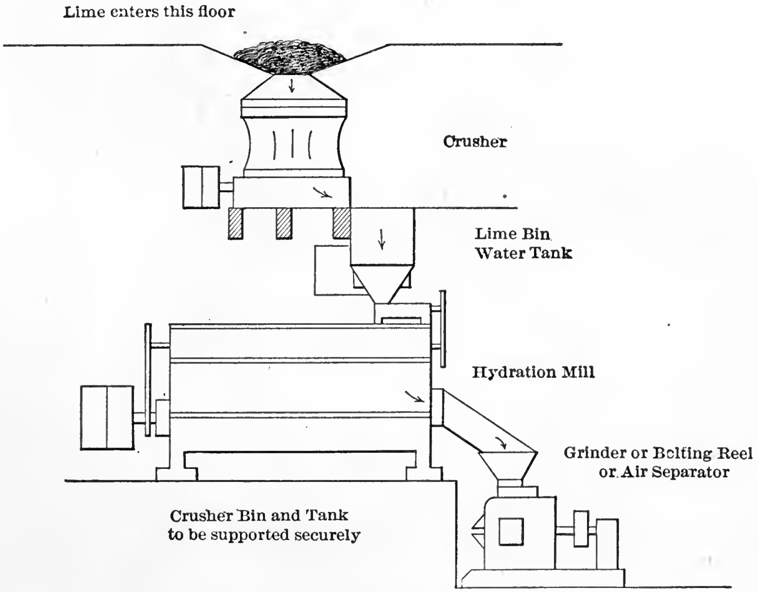

FIG. 24.—Ellis lime-hydrating system.

to the water at once, or part may first be mixed with an excess of water and then the remainder of the lime added. In the well-known Dodge process the first plan is followed. In the Eldred process (U. S. Patent 721,871), in which the second plan is followed, the average amount of lime handled at one slaking is half a ton (1000 lbs.). Of this amount about 400 lbs. is first mixed and slaked with 450 to 500 lbs. water, and then the remaining 600 lbs. of quicklime is added to the resulting paste. A slaking-pan of the Walker & Elliott type is used.

The Campbell hydrater, shown in Fig. 25, has been successfully used at several lime-hydrating plants. The following data on its size, capacity, power, etc., are taken from a recent catalogue of the Clyde Iron Works.

Table 44.

CAPACITY, POWER, ETC., OF CAMPBELL LIME-HYDRATER.

No.	Diameter of Pan.	Height of Pan.	Capacity per Batch.	Pulley.	Speed, R. P. M.	Weight.
2	8 ft. 0 in.	16 in.	1000 lbs.	6×24 in.	175	4500 lbs.
3	10 " 6 "	20 "	2000 "	6×24 "	175	6800 "

The amount of water used will vary with the character of the lime. If it is a pure high-calcium lime, more water is added than if it contains any considerable percentage of either magnesia or clayey matter. In one process, for example, 55 lbs. of water is added to each 100 lbs. of high-calcium lime, or 30 lbs. water to 100 lbs. magnesian lime.

Sieving the product.—After slaking the product is usually stored in bins for forty-eight hours or so, after which it is ready for use. Before packing, however, the coarser particles are removed either by screening or through use of an air separating device. When screens are used, a 50-mesh is the common grade, the pitch of the screen surface being changed to obtain whatever fineness is required. The Jeffrey Columbian Separator, which has been used for this purpose, is described in the table below.

Table 45.

DETAILS OF JEFFREY SEPARATOR.

Number of Machine.	Width Over All.	Length Over All.	Height Over All.	Size of Main Driving Pulley.	Speed of Main Driving Pulley.	Size of Screening Surface.
0	7 ft. 3½ in.	6 ft. 11¼ in.	7 ft.	12 in.×4 in.	250 rev.	4 ft.×6 ft.
2	11 " 3½ "	6 " 11¼ "	7 "	12 " ×4 "	250 "	8 " ×6 "

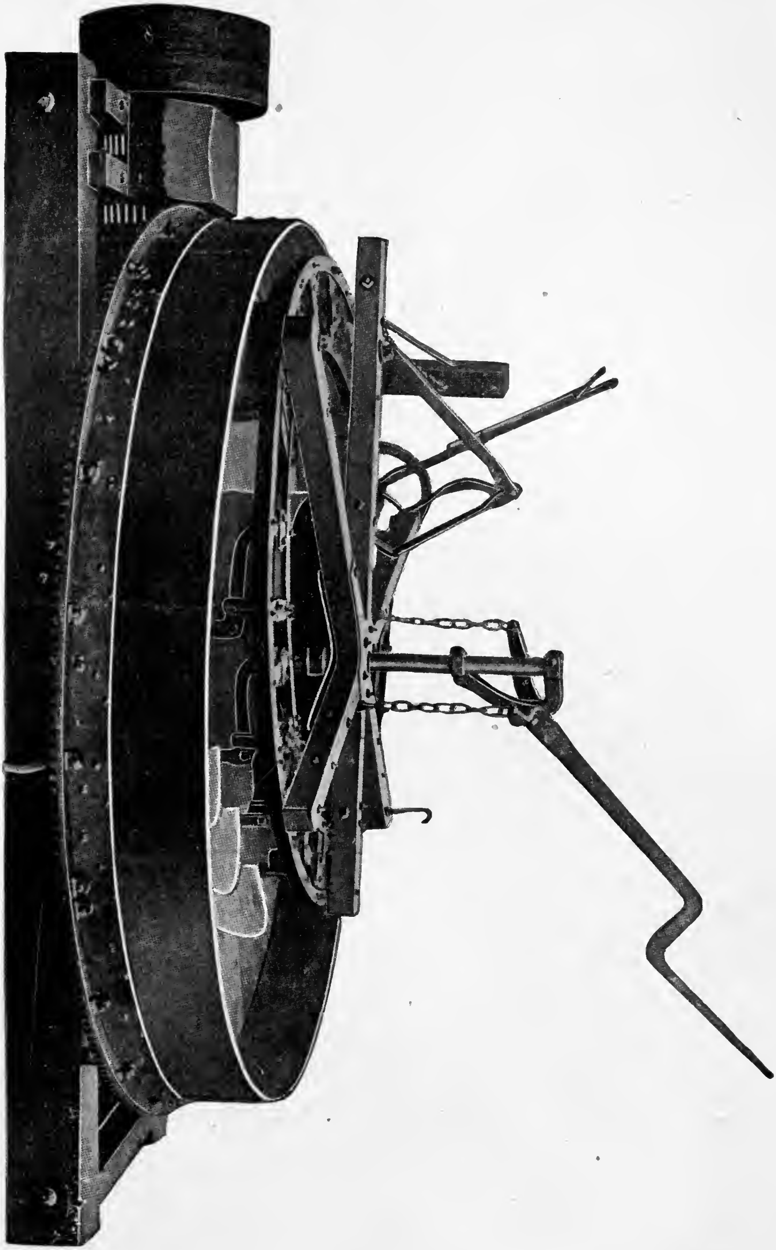

Fig. 25.—Campbell lime-hydrater. (Clyde Iron Works.)

STANDARDS FOR PACKING, ETC.—At a meeting of the hydrated-lime manufacturers of the United States, held in July, 1904, the following standards for packing and selling the product were adopted.*

Bags.—A heavy, closely woven burlap or duck bag, containing 100 lbs., 20 bags to the ton. A paper bag containing 40 lbs., 50 bags to the ton.

Quotations.—All quotations are made including the cost of the package, no bulk quotations being made.

Returned sacks.—The burlap or duck bags will be repurchased from the customer at ten cents each when returned to the mill in good condition, freight prepaid.

Terms of settlement.—A discount of 1 per cent will be allowed for cash in ten days, the discount to be taken on the full price, including the bags f. o. b. manufacturer's plant or shipping-point. Net cash thirty days.

COST OF EQUIPMENT.—The following estimate of cost of equipment, etc., has been furnished by Mr. B. E. Eldred:

Product per hour	5 tons	10 tons
Cost of plant and equipment	$8,000	$10,000
Men required for operation	4–5	6–8
Maximum power required	35 H.P.	50 H.P.
Average power throughout day	15 "	20 "

In estimating the cost of lime hydrating, it should be recollected that the product gains greatly in weight during the process. A ton of quicklime (2000 lbs.) will give from 2400 to 2600 lbs. hydrated lime.

Tests of hydrated lime.—The following tests of two kinds of hydrated lime, while made principally for the purposes of comparing high-calcium with magnesian limes, will serve to give an idea of the tensile strength of hydrated lime in general.

TABLE 46.

TENSILE STRENGTH OF MAGNESIAN AND NON-MAGNESIAN HYDRATED LIME.

Kind of Lime.	4 Weeks.	8 Weeks.	3 Months.	4 Months.	6 Months.
Magnesian lime	8 lbs.	17 lbs.	$37\frac{1}{6}$ lbs.	51 lbs.	83 lbs.
High-calcium lime	$30\frac{2}{3}$ "	$36\frac{3}{5}$ "	$39\frac{1}{4}$ "	39 "	$50\frac{5}{6}$ "

Engineering News, vol. 51, p. 543. June 9, 1904.

The tests above quoted were made by Mr. S. T. Brigham on hydrated lime prepared by the Dodge process. The mortar in each case was

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* Engineering News, vol. 52 p. 220, Sept. 8, 1904.

composed of two parts by weight of sand to one part of slaked lime, and the results are given in pounds per square inch.

Mixture of hydrated lime and Portland cement.—Among the most interesting features of this new product are the results obtained by mixing slaked lime with Portland cement. This mixture has been tested by several experimenters, and the results of the tests are quoted and discussed both by Sabin and Thompson in their recent books on cements and concretes. The addition of hydrated lime to a Portland cement mortar renders it more plastic and easier to work. When this addition does not exceed 10 or 20 per cent an actual increase in tensile strength seems to be shown.

List of references on hydrated lime.

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CHAPTER X.

MANUFACTURE AND PROPERTIES OF LIME-SAND BRICKS.

THE term lime-sand brick will be used in this volume to cover all bricks made by mixing sand or gravel with a relatively small percentage of slaked lime, pressing the mixture into form in a brick mold, and drying and hardening the product, either by sun-heat or artificial methods. The general process is not in any way patentable, being of very ancient date. Various details of the process may, however, be covered by valid patents, such, for example, as on the type of molding-press used, on the exact methods and appliances for drying and hardening, and on various more or less "secret" compounds which may be added to facilitate hardening or to increase the final strength of the product.

Early history of the industry.—Though in the past few years the "invention" of lime-sand brick has been heralded as a new matter, the general process has been employed for many years both in America and in Europe.

The following interesting contemporary account * of the manufacture and use of lime bricks in New Jersey in 1855 incidentally establishes the fact that the industry had been known near Philadelphia since 1838.

"*Gravel bricks.*—A new building material has been introduced in Cumberland and some of the adjoining counties which promises to be both cheap and durable. The common clean gravel and coarse sand of the country is mixed with one twelfth its measure of stone lime and made into bricks. These bricks are sun-dried and then laid up into walls. They are cheap, durable, and but little affected by the changes of the seasons.

"In making, the gravel is laid on a common mortar bed, and the lime, which is slaked and made into a thin putty in a lime-trough, is then run on the gravel and the whole worked up into mortar. The

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* Cook, G. W., in Second Ann. Rept. of the Geol. Surv. of the State of N. J. for the year 1855, pp. 107–108. 1856.

bricks are usually made as large as is convenient for handling and of dimensions to suit the work for which they are intended. The molds are made, several in the same frame, as deep as the thickness of the brick and without any bottom; they are set on smooth ground and filled with mortar. This is worked in a little with the shovel and struck off at the top. In ten or fifteen minutes the mortar will have set, so that the molds can be taken off. The bricks are soon dry enough to handle, when they can be piled up and allowed to dry thoroughly. They are laid in mortar similar to that from which the bricks are made, and the outside of the buildings are roughcast with the same.

"Several buildings of this kind have been erected in Bridgeton and its vicinity within the last eight or ten years, and in Norristown, Pa., it has been in use for seventeen years past. It has stood well, growing harder and more solid every year. The bricks have come to be a regular article of manufacture in several places. Those of 12″×9″×6″ were selling in Bridgeton last summer for $20 a thousand, and they could be laid, and mortar found, for $10 a thousand, which is less than half the cost of the same measure of red-brick wall. The material of which these bricks are made being found almost everywhere, and the labor of making and laying them up being very simple, farmers and others who have control of labor can make and lay them at times when the expense of the work would not be felt, and thus a saving much greater than that mentioned could be made. When first laid up they are not quite as strong as other bricks, and greater care is necessary in making a solid foundation, otherwise unequal settling and cracks in the walls will result. Care must be taken to make them so early in the season as to be entirely dry before the winter's frost."

It will be seen that the general process of lime-sand brick manufacture is well covered by the above description, and that both the merits and defects of the product are stated rather more frankly than is the practice among its advocates to-day. It is to be kept in mind, however, that the lime-sand brick manufacturers to-day claim that their product derives its hardness, not from a simple recarbonation of the lime, but from a more or less thorough combination of the lime with the silica of the sand or gravel. As this is a matter of interest and importance, it will be discussed in some detail on a later page (p. 133).

Whatever the value of their contention may be, it is evident that even this improvement has been anticipated. That a "lime-silicate" brick of modern type was made about 1850 is proven by the following quotation of that date:

"Recent improvements in the manufacture of concrete building blocks have so far perfected the product as to bring this stone into successful competition with the very best of the natural and artificial building materials. The action of lime upon silica, forming a silicate of lime (*calcmakit*), and thus binding together particles of sand, as in mortar, has been known from the remotest ages, and concrete walls of great antiquity are now standing, vying with the natural rock in hardness and durability. Some years since a concrete block, compacted by pressure, was brought out in this country and used to some extent as a building material, but the slowness of the induration and uncertainty in the product hindered its general introduction. The improvements referred to consist in the use of heat in connection with quicklime and sand, by which the formation of the silicate of lime is hastened, and the same effect, which formerly took years to be consummated, is now produced in a few days. Ground quicklime is thoroughly mixed with clean, sharp sand, and is then subjected to the action of either superheated or high-pressure steam, which slaks the lime and causes it to attack the silica. This process continues for from twenty minutes to ten days, according to the degree of heat employed, when the material is molded and compressed by a heavy steam-hammer into blocks of any desired form. The ordinary building-block made by this process is 10 inches wide and 4 inches deep, having a hollow space in the center 6 inches long by 1 inch broad; when the blocks are placed upon each other, so as to break joints, a continuous and connected series of air-chambers will be formed within the wall. Thirty days' exposure of the block, after it is first formed, to the air, produces an induration quite sufficient for all ordinary building purposes, but the block continues to harden for an unlimited period. A church built entirely of this material was recently dedicated at Morrisania. A number of fine buildings have already been constructed of this material in Chicago, among which may be mentioned a handsome block of dwellings on Sixteenth Street, and the Young Men's Christian Association of the same city, which was recently burned. The endurance of this stone when submitted to repeated freezing and thawing is quite remarkable, and experiment proves it to be equal in this respect to granite."

The theory of lime-sand brick.—When ordinary quicklime is slaked, mixed with sand, and used as mortar the mixture hardens very slowly and never attains much strength. The hardening is due to the fact that the slaked lime gradually absorbs carbon dioxide from the atmosphere and recarbonates, forming a sort of artificial limestone. So far as known, there is no chemical action between the lime and the sand of the mortar, though occasionally the statement is made that with increasing age a certain amount of chemical action does take place, resulting in the formation of a certain percentage of lime silicate. This, however, is more than doubtful.

In making lime-sand brick by modern processes, it is claimed by its advocates that the lime and sand of the brick *do* combine to form lime silicates, the combination being in this case brought about through the action of steam under high pressure. It is also claimed, though rather by suggestion than by direct statement, that these lime silicates make up a considerable proportion of the entire mass of the brick.

To the present writer the first claim does not seem to be justified. No proofs have been presented that, in the course of lime-sand brick manufacture, any chemical combination takes place between the lime and the sand. It is undoubtedly true that the treatment with steam under pressure increases in some unexplained way the chemical activity of the slaked lime; but further than that we cannot go at present.

The second point, regarding the percentage of lime silicate which would be formed *if* chemical combination of lime and silica took place, can be readily settled. The lime and silica *might* unite in any one of three proportions, forming respectively the calcic silicate ($CaO.SiO_2$), the dicalcic silicate ($2CaO.SiO_2$), or the tricalcic silicate ($3CaO.SiO_2$). The last of these is the one which is formed during the processes of manufacture of Portland cement, and is the hydraulic silicate *par excellence.* In most sand-lime brick literature a similarity between that product and Portland cement is suggested, even if not definitely claimed. In the little table below the percentage composition of these three lime silicates is presented. It will be seen that the tricalcic silicate contains 73.59 per cent lime to 26.41 per cent silica, while the proportion of lime decreases until it reaches 51.84 per cent in the unicalcic silicate.

TABLE 47.

PERCENTAGE COMPOSITION OF VARIOUS LIME SILICATES.

Compound.	Per Cent CaO.	Per Cent SiO_2.
$CaO.SiO_2$.	51.84	48.16
$2CaO.SiO_2$. . . .	65.01	34.99
$3CaO.SiO_2$. . . .	73.59	26.41

The bearing of these facts upon lime-sand brick manufacture is obvious enough.

The amount of slaked lime used in making lime-sand brick will amount to 5 to 10 per cent of the whole mass, averaging about 8 per cent. If *all* of this 8 per cent of lime be combined with silica in the richest possible silicate ($CaO.SiO_2$), it will take up only 7 per cent of sand. So that on the most hopeful possible basis only 15 per cent of the brick would have any binding properties, the remainder being merely uncombined and inert sand.

General processes of lime-sand brick manufacture.—The general processes involved in the manufacture of lime-sand brick are, in order, as follows:

a. Slaking the lime.
b. Mixing the lime and sand.
c. Pressing the mixture into molds.
d. Hardening the brick.

Necessary properties of the sand.—All the sand should pass a 20-mesh screen, and it is desirable that part of it (say 10 per cent) should be fine enough to pass a 150-mesh screen. Clayey material in the sand is detrimental to the strength of the brick made from it. The composition of the sand grains themselves probably has little influence on the *strength* of the resulting brick; but in order to secure a light and uniform color it is desirable that the sand should consist almost entirely of grains of quartz and that the dark silicate minerals (hornblende, garnet, mica, etc.) should be present in no great quantity.

In testing the influence of size of sand, Peppel * used mixtures in various proportions of two sands. These gave the following results on sieving:

	Coarse Sand.	Fine Sand.
20- to 40-mesh........	50 per cent	
40- “ 60- “	33 “ “	
60- “ 80- “	7 “ “	
80- “ 100- “	7 “ “	
100- “ 120- “	2 “ “	$\frac{7}{10}$ per cent
120- “ 150- “	1 “ “	1 “ “
150- “ 200- “	....	$1\frac{1}{4}$ “ “
Passing 200-mesh........	....	$93\frac{1}{20}$ “ “

The coarse sand was a very pure sharp glass sand; the fine sand was crushed quartz. Made up into bricks with 5 per cent of lime the results shown in the following table were obtained.

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* Trans. Amer. Ceramic Soc., vol. 5. Page 4 of pamphlet edition.

TABLE 48.

EFFECT OF FINENESS OF SAND. (PEPPEL.)

Composition of Sand Mixture by Parts.		Crushing Strength, Pounds per Square Inch.	Tensile Strength, Pounds per Square Inch.
Coarse.	Fine.		
8	2	3114	131
4	2	2955	144
3	2	2461	224

These tests show that the bricks decrease in compressive strength and increase in tensile strength as the amount of fine sand in the mixture increases. These results of themselves appear to be unfavorable to the contention of lime-sand brick manufacturers, that the strength of their product is due to chemical reactions between the sand and the lime. For if this contention were true, the finer sand particles would certainly be more active chemically than the coarser grains, and an increase in fineness of sand would necessarily mean more extensive chemical inte action and consequently greater strength in *both* compression and tension.

Drying the sand.—In order to secure uniformity in the product it is desirable that the sand should be dried before mixing with the lime. So far this point has not been realized by many manufacturers, who are content to use the sand as it comes from the pit—at one time practically dry, at another carrying 10 to 15 per cent of moisture.

As to methods of sand-drying, considerable differences in practice exist. In the Schwarz machine, described and figured on page 137, the sand is placed in a steam-jacketed drum, the drying being aided by revolving paddles which stir up the sand. At a number of plants live or exhaust steam is used in pipe-dryers, the sand being shoveled on a series of horizontal pipes filled with steam. The best practice is probably to use a rotary dryer. At one plant * a direct-heat rotary dryer 22 inches in diameter and 22 feet long, set at a slope of about $\frac{1}{4}$ inch to the foot, dries 40 to 50 yards of sand in ten hours with a fuel consumption of 700 lbs. coal. At another, a 30-foot dryer set at a slope of about $\frac{1}{8}$ inch per foot, with a fan to induce draft, is handling 40 to 50 yards sand in ten hours with a consumption of 600 to 800 lbs. coal.

Necessary properties of the lime.—The lime should be carefully and thoroughly slaked, and should be as free from impurities as possible. The presence of more than a few per cent of clayey matter or iron oxide

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* The Clay Worker, vol. 42, p. 588. 1904.

is undesirable, not so much because of its effect on the strength or durability of the brick as because of its effect on the color.

The following experiments on high-calcium *vs.* magnesian limes appear to prove that the latter give bricks inferior in strength. In view of the results attained elsewhere, however, those in the table below should be accepted with caution.

TABLE 49.

COMPARATIVE TESTS OF HIGH-CALCIUM AND MAGNESIAN LIME BRICKS. (PEPPEL.)

Lime Used.	Amount.	Tests of Strength.				Per Cent of Water Absorbed.
		After Hardening.		After Freezing.		
		Compression, Pounds per Square Inch.	Tension, Pounds per Square Inch.	Compression, Pounds per Square Inch.	Tension, Pounds per Square Inch.	
High-calcium....	....	7745	437	9007	371	8.62
Magnesian.......	....	5187	286	5853	314	9.11

Trans. Amer. Ceramic Soc., vol. 5. Page 15 of pamphlet edition.

The lime-sand bricks whose results are shown in the above table were made up of two parts coarse sand and one part fine sand, to which base was added 10 per cent of lime. The blocks were molded under a pressure of 15,000 lbs. per square inch and hardened by exposure for four to fourteen hours to a steam pressure of 150 lbs. per square inch at a temperature of 185° C. Each of the results given in the table is the average of twelve tests.

Methods of slaking the lime.—The lime may be either slaked to a paste by the addition of more water than is theoretically required or slaked to a dry powder. The general methods employed are usually similar to those in the lime-hydrate industry. In one process, however, a machine of entirely different type is employed, which requires some notice.

The Schwarz process is described * as follows:

"The first operation in the Schwarz process is the mixing of the sand and lime, which is done in a vacuum mixing-machine. This machine is shown in transverse and longitudinal section in Fig. 26. Briefly described, the machine consists of a steam-jacketed drum with interior rotary blades operated by suitable gearing outside and at one end. This drum, which has a capacity of about three tons of sand,

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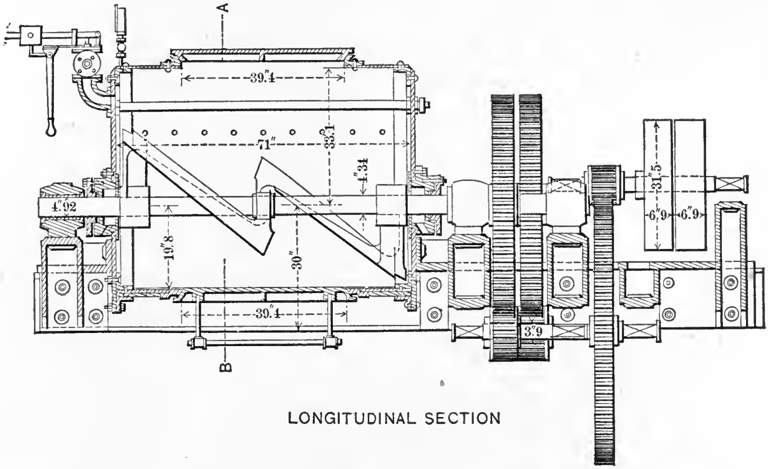
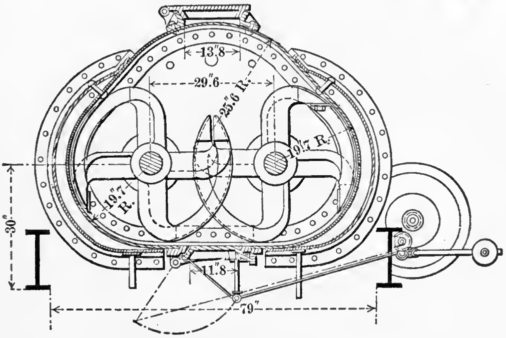
* Engineering News, vol. 49, p. 179. Feb. 19, 1903.

is filled by means of a funnel placed above it. When the drum is charged, the interior mixing-blades are set in motion and the contents are heated by means of the steam-jacket surrounding the drum. A vacuum pump attached to the apparatus removes the steam and air from the drum. When the sand has been properly dried the required quantity of finely pulverized lime is introduced into the drum through



LONGITUDINAL SECTION



CROSS SECTION A-B

Fig. 26.—Schwarz drying- and mixing-machine.

a special aperture and the mixture is again stirred and heated. The necessary quantity of moisture is then introduced into the drum in the form of water or steam by means of a pipe penetrating the interior of the drum. After wetting, the mixture continues to be stirred and heated during a sufficient time to allow a preliminary combination of the lime and sand to take place and produce a mixture with sufficient tenacity to permit of easy molding."

Proportions of mixture.—The slaked lime is mixed with sand in the usual proportion of 5 to 10 lbs. of lime to 100 lbs. of sand. Peppel experimented on this point by preparing mixtures carrying various proportions of lime and sand. His results are shown in the following table.

TABLE 50.

EFFECT OF PERCENTAGE OF LIME. (PEPPEL.)

Composition of Mixture.			Strength in Pounds per Square Inch.					
			After Hardening.		After Aging.		After Freezing.	
Coarse Sand.	Fine Sand.	Lime.	Compression.	Tension.	Compression.	Tension.	Compression.	Tension.
60 lbs.	40 lbs.	5 lbs. magnesian lime. . .	3697	427	. . . . .	. . . . .	3812	
60 "	40 "	10 " " " . . .	5607	503	5843	446	7525	417
60 "	40 "	5 lbs. high-calcium lime	2636	194				
60 "	40 "	40 " " "	7018	541	7153	622	7995	516

Trans. Amer. Chem. Soc., vol. 5. Page 13 of pamphlet edition.

The mixture may be accomplished in pug-mills, edge-runner mills, wet pans or dry pans.

Methods of molding.—The mixture is shaped into bricks in a press. Peppel states * that a press should fulfil the following requirements:

"(1) The press must be able to regularly deliver a pressure of from 200 to 250 tons per brick and yet not break down if by accident the pressure rises somewhat higher.

"(2) The filling of the mold must be accomplished with great accuracy and uniformity.

"(3) All working parts must be so arranged that they will be free from contact with loose sand, otherwise they will cut out at an alarming rate.

"(4) The dies and mold linings must be made of the hardest material obtainable."

Many presses, both of American and German design, are now on the market for use in the lime-sand brick industry. Any machine that will press clay brick has power and strength enough to handle lime-sand brick, but the new product is so fragile as to require delicate handling in taking off the press.

Methods of hardening the bricks.—Three general types of hardening processes have been in use. These are: (1) hardening by simple exposure to the atmosphere; (2) hardening in an atmosphere saturated with carbon dioxide; (3) hardening in a cylinder filled with steam under pressure.

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* Trans. American Ceramic Society, vol. 5, pp. 33–35 of pamphlet edition.

The first of these processes is slow, since the hardening takes place only as rapidly as the lime in the brick can absorb water and carbon dioxide from the atmosphere. The second process is more rapid, but the change of slaked lime to lime carbonate is still incomplete. In the third process, which is the one used at practically all lime-sand brick plants to-day, the reactions are rapid, and its advocates claim in addition that the steam under pressure causes the combination o the lime with the sand, so as to form a greater or lesser amount of silicate of lime. The truth of this contention seems to be more than questionable; but the process is in increasing use and therefore demands a somewhat more detailed description.

In the process as now followed, the bricks are loaded onto trucks and these are run into a long horizontal cylinder. This hardening cylinder is then closed and steam under pressure is admitted.

The experiments, whose results are given in table, were undertaken by S. V. Peppel to determine the most advantageous steam pressure and time of hardening. In discussing these results, Peppel states that "this table shows that four hours' time at 150 lbs. steam pressure is sufficient; that six or eight hours are required at 120 lbs.; that eight to twelve hours are required at 100 lbs."

To the present writer, however, the table seems to show that very little relation of any kind exists between pressure and time and the strength of the resulting brick.

TABLE 51.

EFFECTS OF STEAM PRESSURE AND TIME OF HARDENING. (PEPPEL.)

Strength in pounds per square inch.

Steam Pressure, Pounds per Square Inch.	Hours in Steam.	A.		B.		C.		D.		E.	
		Compression.	Tension.	Compression.	Tension.	Compression.	Tension.	Compression.	Tension.	Compression.	Tension.
150	4	7896	544	5303	392	5282	591	4514	470	4441	330
150	6	7994	390	5045	199						
150	8	7404	509	4957	262	6170	632	4249	430	4491	337
150	10	7767	464	4902	284						
150	12	7514	337	5064	250	6165	556	4543	434	4924	349
150	14	7894	380	5849	329						
120	4	6989	......	5989	......	5403	......	4300	......	5760	
120	6	7063	......	6495							
120	8	8545	......	6038	......	5868	......	5142	......	6718	
100	4	6385	......	5921	......	4280	......	4048	......	4588	
100	6	7566	......	6507	......	5564	......	4456	......	6544	
100	8	7494	......	5753							

Trans. Amer. Ceramic Soc., vol. 5. Page 25 of pamphlet edition.

The hardening cylinder, according to Peppel, should be constructed of ⅝ to ¾ inch iron or steel plate. The cylinder is bricked in to prevent radiation and has one removable end or head. This head "should be handled by an overhead crane or a block and tackle. Hinged doors with a wheel on the bottom and a track for the wheel to run on have been used. These are clumsy affairs to move and occupy much space, and should never be recommended. The bolts should be so fastened to the cylinder that the head can readily be swung into place. These bolts are usually 1¼ to 1½ inches in diameter". The cylinder varies in length from 35 to 67 feet, and in diameter from 5½ to 7 feet.

Costs of plant and manufacture.—The following estimates of cost of plant and production are given by Peppel: *

Cost of Plant for 40,000 Brick per Day. (Peppel.)

Land and buildings	$15,000
1 wet-pan	1,000
1 ball-mill	500
2 presses	4,400
2 pug-mills	800
Conveyors	6,000
Shafting and belting	3,000
1 100-H.P. Corliss engine	2,500
2 100-H.P. boilers	2,000
1 25-H.P. boiler	300
4 hardening-cylinders 7′×60′	8,000
Erecting and insulating cylinders	1,000
Pipes for preliminary heating	1,000
Railroad tracks, etc.	4,500
	$50,000

Cost of Manufacture, 40,000 Brick. (Peppel.)

Sand: 157 cubic yards at $0.07	$11.00
Lime: 11 tons at $4.00	44.00
Coal: 3 tons at $2.25	6.75
Repairs	5.00
Oil and grease	3.00
Labor: 40 men at $1.35	54.00
Foreman at $2.50	2.50
Office expenses	20.00
Depreciation and interest, 12 per cent	20.00
	$166.25
Selling expenses, 10 per cent	16.00
	$182.25
Cost of brick per thousand	$4.55

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* Trans. Amer. Ceramic Soc., vol. 4.

With these estimates may be compared the following data on costs of production, gathered from various sources:

The Huennekes Company, in advertising their system of lime-sand brick manufacture, state that an output of 20,000 brick per day of twenty-four hours will require

Labor:
- 1 engineer
- 1 fireman
- 8 laborers

Material:
- 3 tons coal
- 2½ tons lime
- 50 tons sand

At a small plant using another system recently visited by the writer, six men operated the mill, exclusive of superintendence. They were distributed as follows: two digging and handling sand, one at the mixer, two at the press, and one at the engine. A 30-H.P. engine sufficed to run two pan-mixers, two screw-mixers, one elevator, and one brick-press, and gave a product of 10,000 brick per day of twenty-four hours. Sand-beds occur near the plant, but lime is expensive, being bought in the hydrate form and carried by rail for over 400 miles. Coal is also expensive. Neither labor nor machinery is particularly efficient, and repairs and supplies must therefore be allowed for at rather a high figure. The finished brick are not of very good grade, but can be sold in absence of competition from a really good clay brick at $8.00 to $9.00 per thousand.

The following is probably a fair estimate of the cost of manufacturing lime-sand brick at this plant:

Lime, 1½ tons at $8.00 per ton	$12.00
Coal, 1½ tons at $4.25 per ton	6.38
Labor, 6 men	8.75
Superintendence and office expenses	10.00
Repairs, supplies, etc.	2.00
Interest, depreciation, etc.	6.00
Cost per 10,000 brick	$45.13
Cost per thousand	4.51

At a recent convention * of sand-lime brick manufacturers, several partial estimates of cost of manufacture were submitted. One estimate put the total cost of manufacture at $5.00 per thousand brick, allowing for coal at $4.25 per ton, lime at 80 cents per barrel, and sand at 60 cents per yard. Another placed the total cost at $3.60 per thousand, with slack coal at $1.45 per ton and lime at 40 cents per barrel.

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* Proceedings of the 1st Annual Convention, National Assoc. Mfrs. Sand-Lime Products, reported in the "Clay Worker", vol. 42, pp. 582–591. Dec. 1904.

A third, slightly more detailed, gave the following figures for a plant of 15.000 capacity.

Sand and lime	$1.10
Labor	1.75
Fuel and repairs	0.50
Fixed charges	1.00
Total cost per thousand	$4.35

Composition of lime-sand bricks.—Lime-sand bricks will usually range in composition between the following limits:

Silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3)	85–95 per cent
Lime (CaO) and magnesia (MgO)	9– 3 “ “
Water	6– 2 “ “

The bulk composition of the product is therefore a fairly definite matter and not subject to discussion. The point concerning which there is a definite disagreement is as to the manner in which the above constituents are combined in the brick. The more ardent advocates of lime-sand brick claim that most of the lime is combined with part of the silica as a calcium silicate, and support this contention by presenting analyses showing the presence of noticeable percentages of soluble silica. In the opinion of the present writer this contention is not proven. All that we know concerning the character and formation of the various silicates of lime seems to point in the opposite direction. So far as known no lime silicate can be formed except at very high temperatures, 900° C. or thereabouts.

Physical properties of lime-sand bricks.—Lime-sand bricks are sufficiently strong, when subjected to direct compressive strains, for all ordinary structural purposes. Many of them, however, are very fragile and require careful handling both in transportation and on the work.

The following comparison has been made * by Peppel between lime-sand bricks and a series of natural sandstones tested by the Wisconsin Geological Survey.

TABLE 52.

LIME-SAND BRICKS *vs.* NATURAL SANDSTONE. (PEPPEL.)

	Lime-sand Bricks.	Natural Sandstone.
Weight per cubic foot	136 lbs.	137 lbs.
Absorption	8 per cent	7.3 per cent
Crushing strength per sq. in.	7745 lbs.	6535 lbs.
Coefficient of elasticity	600,000	165,440

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* Trans. Amer. Ceramic Society, vol. 5, p. 31 of pamphlet edition.

The following series of tests show much lower compressive strength and higher absorption than those above quoted.

The tests summarized in the following table were made in 1901 on lime-sand bricks made on the Huennekes system.

TABLE 53.

PHYSICAL TESTS OF LIME-SAND BRICK. (PITTSBURG TESTING LABORATORY.)

Crushing Strength per Square Inch.	Absorption Test 45 Hours in Water. Per Cent Gain.	Absorption after Freezing Test. Per Cent Gain.	Crushing Strength per Square Inch after Freezing.
3518 lbs.	11.6	12.4	4137 lbs.
4162 "	8.57	8.8	5202 "
3859 "	11.3	11.4	

In making the absorption tests half bricks were used, which were dried thoroughly before being immersed in water. After remaining in water 45 hours, bricks were frozen 4 hours at a temperature of 14° F., then thawed in warm water 12 hours, frozen again at a temperature of 9° F. for a period of 3½ hours, thawed in hot water 3 hours, frozen at a temperature of 12° F. for 3½ hours, and finally thawed in hot water for 12 hours. Final absorption test made and then bricks were again thoroughly dried. Bricks showed no signs of cracking or disintegration.

Another series of tests of brick made by the Ventnor Concrete Co., operating on the Huennekes system, is summarized below.

TABLE 54.

TESTS OF LIME-SAND BRICKS. (U. S. NAVAL ACADEMY.)

Crushing: Size of cube $2'' \times 2'' \times 2\frac{5}{16}''$.

	Total.	Per sq. in.
No. 1	12,580 lbs.	3145 lbs.
No. 2	16,500 "	4125 "
No. 3	10,350 "	2588 "

Absorption: Immersed 72 hours.

	Weight in Grains.			
	Dry.	Wet.	Dif.	Per Cent.
No. 1	1241	1337	96	7.735
No. 2	1270	1375	105	2.275
No. 3	1300	1498	108	7.777

Approximate size of whole brick	$8\frac{3}{8}'' \times 4\frac{1}{8}'' \times 2\frac{15}{16}''$
Approximate weight of whole brick	5 lbs. 14 ounces

One whole brick and one brick broken in four pieces were soaked in warm water and then put in tin cans with sufficient water to cover them and frozen in the open air, the thermometer ranging from 4 degrees to 20 above zero. This was repeated four times, thawing in warm water each time. They were then frozen in salt and ice (temperature being above freezing-point) three times. The entire process did not have any bad results with the whole brick. The pieces scaled a little at the edges, probably due to small pieces loosened by the breaking of the brick. Another brick was placed in open air in a freezing temperature and water allowed to drip and freeze on it until coated with ice without any bad results.

Two specimens of lime-sand brick (Huennekes system) were tested in 1904 by Prof. Marston, giving compressive strengths respectively of 3210 and 2097 lbs. per square inch, and absorptions of 10.9 and 11.0 per cent.

In 1904 Prof. Woolson tested several lime-sand brick made on the Schwarz system, with the following results.

TABLE 55.

COMPRESSION TESTS, LIME-SAND BRICK. (WOOLSON.)

	(*a*)	(*b*)
Height, inches	2.25	2.40
Width, inches	4.13	4.15
Thickness, inches	4.00	4.00
Area, square inches	16.52	16.60
Maximum load, lbs.	59,340	60,300
Ultimate strength, lbs. per sq. in.	3,592	3,633

In Table 56 are given the results of a series of tests made at Charlottenburg on various brands of lime-sand brick made in Germany. It will be seen that these results are very low.

TABLE 56.

PHYSICAL TESTS OF LIME-SAND BRICKS. (CHARLOTTENBURG.)

Crushing Strength in Pounds per Square Inch.			Absorption, Per Cent.
Dry Brick.	Water-soaked Brick.	After Freezing.	
1704	1903	2229	12.0
2215	2073	2300	14.0
4189	3933	4260	9.0
1732	1846	2187	10.6
3710	....	3238	
850	....	1335	
1353	....	1747	
1193	1335	1562	18.3

Trans. Amer. Ceramic Soc., vol. 4.

Summary of the results of tests.—The three American series of tests above quoted (Tables 53, 54, and 55) were made on samples of brick furnished by the manufacturers, and the results of these tests are now used for advertising purposes. It seems fair to assume, therefore, that these results are not inferior to the average run, but are, on the contrary, probably better than the usual American lime-sand brick as found on the market.

The bricks tested at Charlottenburg, on the other hand, were probably selected from marketed products, and are probably fairly representative of the average German product as it reaches the building trade.

The two sets of results have therefore been averaged separately, with the results given below.

TABLE 57.

SUMMARY LIME-SAND BRICK TESTS.

	Strength, Pounds per Sq. In.			Absorption, Per Cent.		
	Max.	Min.	Average.	Max.	Min.	Average.
Average 10 American tests.....	4162	2097	3393	12.4	2.275	8.89
Average 8 German tests.......	4189	850	2118	18.3	9.0	12.78

Comparison with clay brick.—It will be of interest to compare with these the results of a series of tests recently published,* which were made in 1903 by Prof. Woolson in an extensive series of clay bricks. The bricks were all made in New Jersey, and were fair average samples, taken from stock piles. For convenience of references the bricks have been divided into two classes—front brick and common brick—and the two classes are separately averaged in the following table.

TABLE. 58.

SUMMARY OF CLAY-BRICK TESTS. (WOOLSON.)

	Compressive Strength, Pounds per Square Inch.			Absorption, Per Cent.		
	Max.	Min.	Average.	Max.	Min.	Average.
Front brick..................	13,873	5583	8805	8.61	1.34	4.20
Common brick................	11,058	661	3785	15.38	6.89	12.04

Even the common clay brick, therefore, is stronger and denser than the lime-sand brick.

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* Vol. 6, Reports N. J. Geological Survey. Clay Industry, p. 256. 1904.

Comparison with sandstone.—Lime-sand bricks are frequently compared, as to physical properties, with natural sandstones. One example of such a comparison, made by an enthusiastic advocate of lime-sand bricks, is given on page 142 of this volume. In the table below the results of a large number of tests of natural sandstones are summarized.

TABLE 59.

SUMMARY OF TESTS OF NATURAL SANDSTONE.

	Compressive Strength, Pounds per Square Inch.			Absorption, Per Cent.		
	Max.	Min.	Average.	Max.	Min.	Average.
45 Wisconsin sandstones......	13,669	1,658	6,429	15.22	2.00	7.46
9 Pennsylvania "	29,252	11,448	17,225			
6 Massachusetts and Connecticut sandstones..........	16,894	4,945	12,192			
17 New York sandstones......	19,968	4,025	12,893			

Comparing these results with those on lime-sand brick given in table 57 above, it will be seen that the average natural sandstone is far superior in every way to the lime-sand brick.

Statistics.—In its recent revival the lime-sand brick industry in the United States dates back only to 1901, at which date a plant was established at Michigan City, Ind. Since that time numerous plants have been established throughout the country. No accurate statistics, however, are available as regards amount and value of total product. In this connection the latest issue of the "Mineral Resources of the United States" notes that "the sand-lime brick industry, mentioned in the last report, made considerable progress during 1903. Several plants had their product on the market, and quite a number of new plants were built during the year, but the large majority were engaged in preliminary work and put no product on the market though they will undoubtedly be factors in the production of 1904. Returns covering 16 operating plants show a marketed product of 20,860,000 brick, valued at $155,400, an average of $7.45 per thousand. Of these 16 operating plants three were located in Michigan, two each in California, New York, South Dakota, and Texas, and one each in Arizona, Maryland, New Jersey, North Carolina, and Pennsylvania."

List of references on lime-sand bricks.—A number of books and papers dealing with the manufacture and properties of lime-sand bricks are listed below. By far the most important of these, from either a theoretical or industrial point of view, are the two detailed papers by S. V. Peppel.

Gowdy, J. K. Sand bricks in France. U. S. Consular Reports, No. 1547. Jan., 1903.

Kitchell, W. Lime brick manufacture. 2d Ann. Rep. New Jersey Geological Survey, pp. 107–108. 1856.

Marston, A. Tests of sand-lime and sand-cement brick and concrete building-blocks. Engineering News, vol. 51, pp. 387–389. April 21, 1904.

Mason, F. H. Calcareous brick and stone manufacture in Germany. Daily U. S. Consular Report, No. 1765, Oct. 3, 1903.

Owen, W. Patent lime and sand block. Journ. Soc. Chem. Industry, vol. 19, p 147. 1899.

Peppel, S. V. The manufacture and properties of artificial sandstone. Transactions American Ceramic Society, vol. 4, 1903; Engineering News, vol. 49, pp. 70–73, Jan. 22 1903.

Peppel, S. V. Further contributions to the manufacture of artificial sandstone or sand brick. Transactions American Ceramic Society, vol. 5, 1903.

Rochmanow. Basic fire-proof bricks. Thonindustrie Zeitung, vol. 27, p. 108. Abstract in Journal Soc. Chem. Industry, vol. 22, p. 421. 1903.

Schwarz. Sand bricks. Abstract in Journal Soc. Chem. Industry, vol. 21, p. 1183–1184. 1902.

Wolff, L. C. Bricks of lime and sand. Thonindustrie Zeitung, vol. 23, pp. 854–859. Abstract in Journal Soc. Chem. Industry, vol. 19, p. 48. 1899.

Anon. The Schwarz drying and mixing machine for manufacturing lime-sand brick. Engineering News, vol. 49, p. 179. Feb. 19, 1903.

PART III. MAGNESIA AND OXYCHLORIDE CEMENTS.

CHAPTER XI.

SOURCES AND PREPARATION OF MAGNESIA.

MAGNESIA, or magnesium oxide (MgO), though possessing very marked cementing properties, is at present too expensive to be used as a cementing material for ordinary structural purposes. It merits discussion in this volume, however, because (*a*) it is the basis of an extensive magnesia brick industry; (*b*) under certain conditions it posessses hydraulic properties; and (*c*) the facts brought out in a description of the manufacture of magnesia and magnesia brick may serve to throw some light on the vexed question of the part played by magnesia when present in hydraulic cements.

Sources of magnesia.—Magnesia may be obtained on a commercial scale either by burning the mineral magnesite, a natural carbonate of magnesium, or by chemical methods practiced on other natural sources of magnesium salts such as highly magnesian limestones or even sea-water. At present magnesite is by far the most important source of magnesia, but the chemical methods of extraction may be of service under certain commercial conditions. All the sources and methods will therefore be considered in the present chapter, magnesite being first discussed and then the chemical sources of supply. The chapter following will be devoted to consideration of the properties and uses of the magnesia, however obtained, and the manufacture and properties of magnesia bricks.

Magnesite as a Source of Magnesia.

Composition and character of magnesite.—Magnesite occurs commonly as a fine-grained, compact mineral, varying from white to yellowish in color according to its degree of purity. It is hard and brittle; if cold hydrochloric acid be dropped upon it no action takes place, but hot acid causes brisk effervescence.

In composition it is a magnesium carbonate, corresponding to the formula $MgCO_3$. This is equivalent to magnesium carbonate ($MgCO_3$) = magnesium oxide or magnesia (MgO) + carbon dioxide (CO_2). Quantitatively, pure magnesite ($MgCO_3$) consists of 47.6 per cent magnesia (MgO), 52.4 per cent carbon dioxide (CO_2).

Occurrence and origin of magnesite.—Magnesite, when in bodies of workable size, occurs commonly in one of three associations, the methods of origin of the deposits being different in each case. The three types of deposits are:

(1) Magnesite occurs most commonly in the form of irregular veins or pockets in serpentine or other magnesian igneous rocks. In this case the magnesite has been formed as a decomposition product arising from the decay of the igneous rock.

(2) Magnesite occurs in the form of beds associated with deposits of rock salt, gypsum, etc. In this case the magnesite deposit has undoubtedly originated by direct deposition of magnesium carbonate from bodies of concentrated saline waters.

(3) Magnesite also occurs in the form of beds interstratified with shales, limestones, etc. Magnesite deposits of this type are commonly ascribed to the replacement of the lime (in a limestone) by magnesia carried in by percolating waters. This may be true in some cases, but such deposits may also have originated by direct deposition, as described under (2), above.

In most of the workable magnesite deposits noted below, however, the first method of origin is the true explanation.

Distribution of magnesite deposits.—The magnesite deposits now exploited on a sufficient scale to be of commercial interest occur in Austria, Germany, Greece, Hungary, India, and the United States. Workable deposits also occur in Canada, but as yet have not been sufficiently opened up to determine their commerical importance.

Foreign localities. —The principal Austrian magnesite deposits are near Mittendorf, in Styria, and near Tolsvar, in the province of Minsan, Hungary. The Styrian magnesite averages about 88 per cent magnesium carbonate with about 8 per cent of silica, alumina, and iron oxide. The Hungarian product is a purer magnesite, carrying 92 to 95 per cent magnesium carbonate, with 3 or 4 per cent iron oxide.

In Germany the deposits now worked occur near Kosewitz and Frankenstein, in Silesia, and are principally worked in connection with the manufacture of carbonic acid. The product will carry about 92 to 94 per cent magnesium carbonate, the principal impurity being 4 to 5 per cent of silica.

The principal Grecian deposits are on the island of Eubœa, on the east coast of Greece, and also near Corinth. The product is a very pure magnesite, averaging 95 per cent magnesium carbonate. It is low in clayey matter, the principal impurity being 3 to 5 per cent of lime carbonate. The Grecian deposits are worked in primitive fashion by pick and shovel. The mines, or quarries, are usually worked as open cuts. As the rock is broken in the mines it is brought to the surface, where the magnesite is sorted out. It is then loaded into small carts and drawn to a narrow-gauge gravity railway, when the magnesite is loaded into one-ton cars and sent forward to the shipping port, usually Kymassi or St. Theodore. The cost of producing the mineral is about $3.50 per ton, transportation charges to the seaport about $1.00, and freight to the United States about $2.50 per ton.

Magnesite is found in considerable quantity in southern India, about two hundred miles from Madras. Deposits recently exploited extend over 1500 acres. The railroad from Madras to Calicut runs through these deposits, near the center of the magnesite area. The material can be shipped, in any desired quantity, either from Madras on the east coast or from Beypore on the west coast. As described to the present writer by the owner, the magnesite occurs in beds or veins of varying thickness, from a few inches up to several feet, the magnesite beds being separated by bodies of disintegrated material. An analysis of this magnesite is given in column 1, Table 63. This was made on a 100-ton sample of crude rock. Another analysis of Indian magnesite, quoted in column 2 of the same table, accompanied a series of specimens exhibited at the St. Louis Exposition in 1904.

American localities.—The principal American magnesite deposits are in California and in Quebec, Canada.

The California deposits are described * as follows: "The principal producing point in California is in the vicinity of Porterville, Tulare County, though a small quantity still comes from Chiles Valley and Pope Valley, Napa County. At Porterville there are several deposits. The main deposit at the opening carries a small vein, but at the end of the 240-foot tunnel the deposit is 40 feet wide, and there are said to be several million tons now in sight. At this place calcining furnaces have been erected and are in operation. The mineral crops out boldly in

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* Mineral Resources of the U. S. for 1903, pp. 1131–1135. 1904.

distinct veins, having a general strike northeast and southwest, and there are spurs running in several instances at nearly right angles with the primary veins. On the surface the veins are fom 2 inches to 10 feet wide. They cover an area of over 500 acres. In Pope and Chiles valleys, Napa County, there are somewhat extensive deposits which were formerly worked, but hauling by team to railroad made them more expensive to operate than the mines at Porterville. In Placer County there is a more extensive deposit than elsewhere in California, but it is in an almost inaccessible mountain region where a very costly road would be necessary to get the product out, and the deposit has therefore not been utilized. Near Sanger, Fresno County, 7 miles from Centerville, another deposit is now being opened. A deposit has been discovered also near Walkers Pass, Kern County, but it has never been opened. There are also unutilized deposits near Morgan Hill, Santa Clara County.

"The extensive deposits of magnesite on Red Mountain, at a point where Stanislaus, Alameda, and Santa Clara counties join, are now being opened by the American Magnesite Company, of Chicago, which has obtained control of the numerous claims heretofore owned by individuals. None of them have been at all thoroughly prospected as yet, though there are numerous boulders or large croppings, some from 30 to 150 feet wide, supposed to cover extensive beds beneath. The parent company is the American Magnesite Company, organized under the laws of the State of Maine, with Mr. G. Watson French, of Chicago, as president and Mr. H. C. Stillwell, of Fruitvale, Alameda County, Cal., as vice-president and Pacific coast agent; Mr. Charles H. Spinks, of Berkeley, Cal., is to manage the mines. One of the subsidiary companies is the Rose Brick Company, which is to manufacture magnesite brick, at Oakland, Cal.; the American Carbonic Acid Gas Company is another, of which Mr. John Deere is president and Mr. George A. Wayman, manager. The third corporation is the Plastic Construction Company, of which Mr. Edwin D. Weary, of Chicago, is president. This company controls the American rights for making a fire-proof construction material as well as a patent brick. This factory will also be in Oakland.

"The mines of this company are nearly all in Santa Clara County, with a few in Stanislaus, near the Alameda County line. The Alameda County supervisors are building a wagon-road from the mines to Livermore, where the railroad is met. There are twenty-seven mining claims in the group, and several are at present being opened. Only a few car-loads for sample purposes have been shipped since the com pletion of the new organization, but it is expected that the properties will shortly be opened on an extensive scale."

Recently several large deposits of magnesite have been discovered * in the township of Grenville, Argenteuil County, in the province of Quebec. Large boulders of the mineral were found, and finally the magnesite was found in place. One of these deposits, which showed an outcrop 90 feet long and 20 feet broad, is in the north half of the eighteenth lot of the eleventh range of Grenville township. Another outcrop, 100 feet wide and traceable for a quarter mile in length, is on the north half of the sixteenth lot of the ninth range.

The following analyses of magnesite from these deposits were made by G. C. Hoffmann, and are quoted from the report cited below.*

TABLE 60.

ANALYSES OF MAGNESITE FROM QUEBEC, CANADA.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
Magnesium carbonate ($MgCO_3$)	77.62	74.68	78.08	77.16	76.09	76.97	49.71	75.69	82.72	77.07	85.00	95.50	81.27
Calcium carbonate ($CaCO_3$)	16.07	18.89	15.57	10.78	16.00	13.14	30.14	19.71	12.36	16.28	10.80	tr.	13.64
Magnesia (MgO) as silicate	3.50	3.71	4.18	6.14	4.29	5.87	9.17	3.08	2.53	3.22	n. d.	n. d.	3.66

It will be seen that this Canadian magnesite differs from all the other magnesites known to commerce, in that it contains a comparatively large percentage of lime carbonate as its principal impurity.

Production and imports of magnesite.—In the following tables (61 and 62) statistics regarding the domestic production and the imports of magnesia and magnesite are given. It will be seen that in 1903 the value of the United States production amounted to less than 3 per cent of the total value of magnesia and magnesite used in this country.

Analyses of commercial magnesite.—As magnesite is simply magnesium carbonate, a theoretically pure magnesite would consist of 47.6 per cent magnesia (MgO) and 52.4 per cent carbon dioxide (CO_2). Deposits of magnesite, however, rarely yield any considerable amount of material of this degree of purity, and commercial magnesite may contain as high as 10 per cent or thereabouts of lime carbonate, silica, alumina, iron oxide, etc.

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* Ann. Rep. Canadian Geol. Survey, vol. 13, Report R, pp. 14–19. 1903.

TABLE 61.

QUANTITY AND VALUE OF CRUDE MAGNESITE PRODUCED IN THE UNITED STATES, 1891–1903.

Year.	Quantity.	Value.	Year.	Quantity.	Value.
	Short tons.			Short tons.	
1891	439	$4,390	1898	1,263	$19,075
1892	1,004	10,040	1899	1,280	18,480
1893	704	7,040	1900	2,252	19,333
1894	1,440	10,240	1901	3,500	10,500
1895	2,220	17,000	1902	2,830	8,490
1896	1,500	11,000	1903	3,744	10,595
1897	1,143	13,671			

TABLE 62.

IMPORTS OF MAGNESITE INTO THE UNITED STATES IN 1903.

	Quantity.	Value.
Magnesia:	Pounds.	
Calcined, medicinal	34,586	$4,412
Carbonate of, medicinal	10,569	765
Sulphate of, or Epsom salts	2,392,831	11,326
Magnesite:		
Calcined, not purified	73,534,690	311,396
Crude	36,017,637	150,002

TABLE 63.

ANALYSES OF MAGNESITE.

	1.	2.	3.	4.	5.
Silica (SiO_2)	2.20	0.22	0.30	0.52	0.52
Alumina (Al_2O_3)	0.30	0.30	1.62	trace	0.08
Iron oxide (Fe_2O_3)					
Lime (CaO)	0.59	n. d.	n. d.	2.25	2.46
Magnesia (MgO)	46.59	47.35	46.00	45.28	44.96
Carbon dioxide (CO_2)	49.63	51.44	51.23	51.61	51.44
Water	0.83	0.27	n. d.	0.34	0.54

	6.	7.	8.	9.
Silica (SiO_2)	1.0	4.00	0.8	4.5–5.25
Alumina (Al_2O_3)	3.0–6.0	4.00	1.1	1.5
Iron oxide (Fe_2O_3)			3.2	
Lime (CaO)	0.28–1.12	n. d.	0.06	0.6–0.7
Magnesia (MgO)	42.84–45.70	41.89	45.12	46.0–48.0
Carbon dioxide (CO_2)	n. d.	n. d.	49.72	46.0–50.0

1. 200 miles from Madras, British India. Private communication.
2. India. Indian Exhibit, World's Fair, St. Louis, 1904.
3. Dept. of Ufa, Southern Urals, Russia. "Mineral Industry," vol. 10, p. 439.
4. Mondondi, Greece. U. S. Consular Reports, No. 168, 1900.
5. Eubœa, Greece. Proc. Inst. C. E., vol. 112, p. 381.
6. Styria, Austria. Proc. Inst. C. E., vol. 112, p. 381.
7. Styria, Austria. Eng. and Mining Journal, March 10, 1900.
8. Minsan, Hungary. Eng. and Mining Journal, March 10, 1900.
9. Frankenstein, Silesia (Germany). Eng. and Mining Journal, March 10, 1900.

Effects of heating magnesite.—If magnesite ($MgCO_3$) be strongly heated, the effect (as with lime carbonate) is to drive off the carbon dioxide (CO_2), leaving magnesia (MgO) as a white solid. A curious and technologically important phenomenon connected with the temperature employed is to be noted. If the calcination be carried on quickly at a red heat, the magnesia resulting will have a specific gravity of 3.00 to 3.07; while if the calcination is long continued or carried on at a higher temperature the resulting magnesia will be much denser, possessing a specific gravity of 3.61 to 3.80.

The technologic importance of the two forms of magnesia lies in the fact that the lightly burned magnesia will slake with water and if then exposed to air will finally recarbonate and harden slowly, just as lime does. The denser, higher-burned magnesia, however, will not take up either water or carbon dioxide from the atmosphere. Another difference of commercial interest lies in the fact that the light form of magnesite possesses a certain amount of plasticity, so that it can be molded into shape under heavy pressure, while the dense form of magnesia is entirely devoid of plasticity.

Methods of burning magnesite.—For calcining magnesite at low temperature, so as to obtain lightly burned magnesia, kilns closely similar to ordinary lime-kilns are employed in California. The kilns in use at one California magnesia-plant are built in the form of a frustum of a cone, the broader part downwards. These kilns are about 19 feet in height, 3 feet in diameter at the top, and 7 feet in diameter at the base. Drawing-doors are placed at the base, while draft is obtained by suction, air being drawn through a flue near the top of the kiln. These kilns are charged with coke and magnesite mixed, in about the proportion of 300 lbs. magnesite to 20 lbs. of coke. The product is the light form of magnesite, and is probably not entirely decarbonated. This fuel consumption would amount to about 14 per cent on the weight of magnesia produced.

When the dead-burnt or heavy magnesia is required, the burning must take place at much higher temperatures. This kind of magnesia may be prepared in reverberatory furnaces, in cupolas lined with silicious material, or in highly heated gas-kilns.*

The practice in Greece is described † as follows:

" At the Greek magnesite mines, until recently roughly built kilns fired by wood were employed for catcining the ore, which required a

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* Proc. Inst. Civil Engineers, vol. 112, p. 381. 1893.

† Engineering and Mining Journal, Feb. 28, 1903

large quantity of fuel. In recent years, however, modern shaft calciners have been built and a soft lignite coal is used. When calcined, magnesite falls into powder and is apt to choke the lower or cooler portion of the kiln, preventing the access of air and heated gases to the upper portion. The shaft furnaces are constructed to overcome this result. The quantity of fuel required is from 15 to 20 per cent of the weight of magnesite, equivalent to a fuel consumption of 30 to 40 per cent on the weight of magnesia produced. In some cases the calcining is done in a double-hearth reverberatory furnace, where the flame is brought into direct contact with the freshly charged magnesite on the upper hearth, the operation being completed on the lower hearth, which is the hotter of the two."

Composition of the product.—The analyses given in Table 64 will serve to show the composition of the burned product, which naturally varies according to that of the magnesite from which it is made.

TABLE 64.

ANALYSES OF CALCINED MAGNESITE (=MAGNESIA).

	1.	2.	3.	4.	5.	6.	7.
Silica (SiO_2)..........	0.98	0.16	0.17	0.50	......	1.2	0.73– 7.98
Alumina (Al_2O_3).......	0.10	0.10	2.38	......	......	13.0	0.56– 3.54
Iron oxide (Fe_2O_3).....	5.70	7.40	5.02	6.50	6.90		
Lime (CaO)...........	1.88	2.66	1.50	1.70	......	7.3	0.83–10.92
Magnesia (MgO)	91.10	89.36	90.42	90.95	91.50	77.6	82.46–95.36
Carbon dioxide (CO_2)...	n. d.	n. d.	0.46	n. d.	n. d.		

1, 2. Burned Hungarian magnesite. Iron Age, Jan. 15, 1903, pp. 20, 21.
3, 4, 5. " " " Mineral Industry, vol. 10, p. 439.
6. " Styrian (Austrian) magnesite. Proc. Inst. C. E., vol. 112, p. 381.
7. " Grecian magnesite. Proc. Inst. C. E., vol. 112, p. 381.

Use of magnesite for preparation of carbonic acid, etc.—California practice in the manufacture of carbonic acid from magnesite is described as follows in a recent report:*

"In the manufacture of carbonic-acid gas, the gas is extracted from the magnesite by calcining and the remaining calcined material is sold to the manufacturers of wood-pulp paper. The best English coke is used for calcining the magnesite. From one short ton of magnesite, after removing the gas, they obtain about 1200 lbs. of residue, which is partly calcined magnesite still carrying some 20 per cent of gas. In the process about 500 lbs. of gas is obtained when finally compressed

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* Mineral Resources of the U. S. for 1903, p. 1133. 1904.

into liquid form. For every ton of magnesite about 500 lbs. of coke is burned, and this, containing about 97 per cent of carbon, also furnishes considerable gas. The steel cylinders for holding the liquid gas are $\frac{3}{16}$ inch thick and 5 by 49 inches long, and hold about 25 lbs. The pressure on the cylinder at 60° F. is about 850 lbs., a three-stage compressor being used. In shipping the liquid gas through the central valleys and to Arizona the heat in the cars sometimes runs as high as 145°, the pressure being increased thereby. The cylinders containing the liquefied gas are shipped to soda-water manufacturers, ice-factories, refrigerating-plants, breweries, bar-rooms, etc. The cylinders with the liquid gas are shipped all over the Pacific coast from San Francisco, even the British war vessels stationed at British Columbia using the gas for their refrigerating-plants. The San Francisco carbonic-acid-gas makers use about 1000 tons of crude magnesite annually.

As stated, the wood-pulp paper-mills of California and Oregon use the calcined magnesite. They transform it into a sulphite of magnesia and use it as a digester for the wood pulp. To make this sulphite they put the material into a tank and pass sulphurous fumes through it. After being used as a digester they add a little lime and make the 'pearl hardening' of commerce to be used as a 'filler' for the paper."

Magnesian Limestones as Sources of Magnesia.

Highly magnesian limestones, approaching dolomite in composition, may be regarded as possible sources of magnesia. The general characters of such limestones are discussed in some detail in earlier chapters of this volume, and reference should be made to pp. 90–91 for data on these points.

Occurrence of magnesian limestones in the U. S.—Magnesian limestones are so widely distributed throughout the United States that no satisfactory summary of their distribution can be given here. On pp. 92–94 is given a list of reports on the limestones of the various states and territories. Reference to these reports will furnish data on the local distribution and composition of magnesian limestones, as well as of other types.

Analyses of magnesian limestones.—In the following table analyses of a number of highly magnesian limestones from various localities in the United States are presented. It will be seen that these range from 15 to over 22 per cent in magnesia (MgO), which is about equivalent to a range of from 32 to 45 per cent magnesium carbonate ($MgCO_3$).

TABLE 65.

ANALYSES OF HIGHLY MAGNESIAN LIMESTONES, U. S.

	1.	2.	3.	4.	5.
Silica (SiO_2)	3.24	7.75	....	0.48	0.08
Alumina (Al_2O_3)	0.17	1.48	....	0.20	0.25
Iron oxide (Fe_2O_3)	0.23		0.02		
Lime (CaO)	29.58	31.00	31.01	31.31	30.46
Magnesia (MgO)	20.84	16.46	21.79	21.03	21.48
Carbon dioxide (CO_2)	45.54	42.47	47.35	46.98	47.58

	6.	7.	8.	9.	10.
Silica (SiO_2)	0.73	0.44	0.87	0.20	0.70
Alumina (Al_2O_3)	0.35	1.22	0.57	0.23	0.95
Iron doxie (Fe_2O_3)		trace	0.25		0.80
Lime (CaO)	32.73	30.73	31.40	30.04	30.50
Magnesia (MgO)	19.37	20.87	19.95	22.28	20.05
Carbon dioxide (CO_2)	46.58	45.85	n. d.	47.14	45.24

1. Morrisville, Calhoun County, Ala. W, F. Hillebrand, analyst. Bulletin 60, U. S. Geol. Survey, p. 159.
2. S. 16, T. 7, R. 7, E. Talladega County, Ala. J. B. Britton, analyst. Rep. Ala. Geol. Survey for 1875, pp. 149, 150.
3. Inyo Marble Co., Inyo, Calif. 20th Ann. Rep. U. S Geol. Survey, pt. 6, p. 359.
4. East Canaan, Conn. 20th Ann. Rep. U. S. Geol. Survey, pt. 6, p. 370.
5. Canaan, Conn. J. S. Adams, analyst. 20th Ann. Rep. U. S. Geol. Survey, pt. 6, p. 370.
6. Jasper, Ga. W. H. Emerson, analyst. Bulletin No. 1, Ga. Geol. Survey, p. 87.
7. Cockeysville, Md. J. E. Whitfield, analyst. Bulletin 60, U. S. Geol. Survey, p. 159.
8. Ossining, N. Y. H. Ries, analyst. Bulletin 44, N. Y. State Museum, p. 829.
9. Tuckahoe, N. Y. Ledoux, analyst. 20th Ann. Rep. U. S. Geol. Survey, pt. 6, p. 427.
10. Gates, Monroe County, N. Y. D. H. Newland, analyst. Bulletin 44, N. Y. State Museum, p. 796.

Extraction of magnesia from magnesian limestone.—Two principal processes have been suggested for extracting magnesia from magnesian limestone.

Scheibler process.—The mixture of lime and magnesia left by burning magnesian limestone is made into a thick milk by adding sufficient water. Into this solution is poured water containing 10 to 15 per cent, by volume, of molasses, and the mixture is mechanically stirred. In a few moments saccharate of lime is formed, which remains in solution while the magnesia is precipitated. On putting through a filter-press the magnesia remains behind, while the saccharate of lime passes through. The composition of the magnesia so obtained at a German plant was:

Silica (SiO_2)	1.47 per cent
Alumina (Al_2O_3)	
Iron oxide (Fe_2O_3)	
Lime (CaO)	2.18 " "
Magnesia (MgO)	95.99 " "

The saccharate of lime which passed through the filters is now treated for recovery of its constituents. Carbon dioxide precipitates the lime as carbonate, after which it is filtered and the lime carbonate precipitate washed. The filtrate contains the molasses, which can be used over again. In the course of the process a loss of 5 to 10 per cent of molasses occurs.

Closson process.—This process is based on the use of magnesium chloride, and is therefore of value at points such as Stassfurt, where that material is obtainable as a cheap by-product.

Twenty thousand pounds of magnesium chloride is mixed with the lime-magnesia resulting from the calcination of 3000 lbs. of magnesian limestone. Water is added to give a thick solution, and mechanical agitation is employed. The result is the formation of lime chloride and magnesia hydrate. On passing through a filter-press the magnesia hydrate is caught on the filter, while the lime chloride passes through in solution. The hydrate is washed and then burned, giving one ton of magnesia. The magnesia obtained at Horde by this process gave the following composition:

Silica (SiO_2)	1.05	per	cent
Alumina (Al_2O_3)			
Iron oxide (Fe_2O_3)			
Lime (CaO)	1.94	“	“
Magnesia (MgO)	96.90	“	“

The lime-chloride solution is then treated for recovery. The material is carried to receptacles like those in which blast-furnace gases are washed, except that revolving wheels stir the chloride, making a thorough mixture of the gases and the liquid. Two of these receptacles are placed together back to back. A valve which can be reversed sends the gases to either side and thus keeps up a continuous working. Into these receptacles, together with the lime chloride, is put a quantity of the lime-magnesia resulting from the calcination of magnesian limestone. The blast-furnace gases passing through precipitate the lime as carbonate, losing their carbon dioxide in the process, and are thus rendered more combustible. They deposit, besides, a considerable quantity of the solid materials mechanically carried by them and are thus cleaned. Magnesium chloride is reformed, remains in solution, and is drawn off and filtered. The entire process shows a loss of 5 to 6 per cent of magnesium chloride.

Sea-water and Brines as Sources of Magnesia.

Sea-water contains small percentages of different magnesian salts. In the manufacture of table salt from sea-water or salt brines, these magnesian compounds are incidentally concentrated so as to be put in more available form.

Extraction of magnesia from sea-water.*—"Magnesia is made out of sea-water, which contains about 4 lbs. magnesium chloride per cubic yard of water, on a large scale at Aignes Morts, on the Mediterranean coast of France.

"The sea-water is pumped into a tank made of masonry, and at the same time milk of lime is pumped in, in the proportion of 1.5 per cent of lime for every 1 per cent of magnesia. From this first tank the liquid flows into two other masonry tanks, when thorough mixing is effected mechanically. It is then filtered into shallow excavations about 1000 feet long and 16 feet wide, in the bottom of which is a bed of clean beach-sand. When enough magnesia has been collected the liquid supply is cut off and the precipitate is allowed to dry. If in summer, it is dried in the sun, taking twenty to thirty days, but in winter artificial drying is necessary." The dried magnesia is then calcined and treated as explained in discussing the burning of magnesite (p. 154), and the manufacture of magnesia bricks (pp. 160–161).

References on magnesite, sources of magnesia, etc.

Hoffmann, G. C. Magnesite deposits in Quebec, Canada. Ann. Rep. Canadian Geological Survey, vol. 13, Report R, pp. 14–19. 1903.
Vlasto, S. J. The magnesite industry [in Europe]. Engineering and Mining Journal, March 10, 1900.
Watts, W. L. [Magnesite in Santa Clara County, California.] 11th Ann. Rep. California State Mineralogist, pp. 374–375. 1893.
Weiss, N. Magnesite in Hungary. Iron Age, pp. 20–21. Jan. 15, 1903.
Yale, C. G. [Magnesite deposits in Cailfornia.] Mineral Resources U. S. for 1903, pp. 1131–1135. 1904.
Anon. Magnesite [in California]. 12th Ann. Rep. California State Mineralogist, p. 328. 1894.
Anon. Magnesite in Greece. U. S. Consular Report, No. 168, 1900.

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* Lock, C. G. W. Economic Mining, p. 331.

CHAPTER XII.

MAGNESIA BRICKS AND OXYCHLORIDE CEMENTS.

After magnesia (MgO) has been obtained by any of the methods described in the preceding chapter, it is put to use in two quite different ways. As the products differ greatly in both composition and use they will here be discussed separately under the headings of "Magnesia Bricks" and "Oxychloride Cements".

Magnesia Bricks.

Magnesia bricks, which are commonly but very erroneously called *magnesite* bricks in the trade, are largely used as furnace linings, etc., and have also been used to a small extent as linings for Portland-cement kilns.

Manufacture of magnesia bricks.—In discussing the methods and effects of calcining magnesite it was stated that two different forms of magnesia could be obtained, according to the temperature at which the calcination is carried on. If the magnesite be burned at a light-red heat, the resulting magnesia will have a low specific gravity (3.00 to 3.07), will possess sufficient plasticity to be capable of being molded into shapes, and will gradually absorb water and carbon dioxide from the atmosphere, just as quicklime would do. The result of this absorption is that this form of magnesia will finally become partly recarbonated.

If the calcination takes place at a higher temperature, however the resulting magnesia will be heavy, with a specific gravity of 3.61 to 3.80; it will be absolutely devoid of plasticity; and it will not recarbonate on exposure to the atmosphere.

These differences in the physical and chemical properties of the two forms of magnesia are taken advantage of in the manufacture of magnesia bricks. Each contributes certain good qualities to the brick.

Magnesia bricks are made of a mixture of the two forms of magnesia, in the proportions of four to six parts heavy magnesia to one part light magnesia. The dense, chemically stable "heavy magnesia" is thus the *base* of the brick; the light magnesia is added to give plasticity to the mixture, enabling it to be molded, and also to harden on exposure to the atmosphere.

From 10 to 15 per cent of water is added to this mixture, and the resulting stiff paste is pressed into form in iron molds. The brick will gradually harden on simple exposure to the air, after which it is usually made still more resistant by reburning at a low red heat. Bricks or other objects made in this manner may, if not sufficiently solid for the use for which they are intended, be hardened by dipping into a cold dilute solution of boracic acid in water. After this they should be dried and reburned.

Composition of magnesia bricks.

TABLE 66.

ANALYSES OF MAGNESIA BRICKS.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	0.35	3.45	3.10	3.4	3.2	2.16
Alumina (Al_2O_3)	....	1.30	6.64	0.98	0.69	0.72
Iron oxide (Fe_2O_2)	6.05	7.60		5.1	0.3	
Lime (CaO)	2.10	3.90	3.76	2.8	1.9	4.20
Magnesia (MgO)	91.52	83.00	86.50	87.8	93.88	93.93
Carbon dioxide (CO_2)	....	....	....	0.04	0.14	

1. Brick made from Hungarian magnesite. Mineral Industry, vol. 10, p. 439.
2. " " " Styrian " " " " " "
3. " " " " " Trans. Am. Inst. Min. Engrs., vol. 26, p. 268.
4. " " " " " Mineral Industry, vol. 10, p. 439.
5. " " " Grecian " " " " " "
6. " " " " " Trans. Am. Inst. Min. Engrs., vol. 26, p. 268.

Physical properties of magnesia bricks.—The brick* whose analysis is given in column 3 of Table 66 was made in Pittsburg from Styrian magnesite. Its specific gravity was 3.44, equivalent to a weight of 160.9 lbs. per cubic foot. The brick whose analysis appears in column 6 of the same table was made from Grecian magnesite. Its specific gravity was 3.54, corresponding to a weight of 170.2 lbs. per cubic foot.

Le Chatelier tested two kinds of magnesite bricks (Austrain and Grecian) for expansion with increase of temperature, obtaining the results quoted in Table 67. The expansions given are in millimeters for a bar 100 mm. in length, and are therefore equivalent to percentages.

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* Trans. Am. Inst. Min. Engrs., vol. 26, p. 268.

TABLE 67.

EXPANSION OF MAGNESITE BRICKS ON HEATING. (LE CHATELIER.)

	200° C.	400° C.	600° C.	800° C.
	mm.	mm.	mm.	mm.
Austrian magnesite brick	0.21	0.55	0.85	1.10
Grecian magnesite brick	0.25	0.52	0.79	1.02

References on magnesite bricks.—The following papers contain data regarding the manufacture and properties of magnesia bricks.

Bischof, C. On magnesia bricks. Proc. Inst. Civil Engineers, vol. 112, pp. 381–383. 1893.

Egleston, T. Basic refractory materials. Trans. Amer. Inst. Mining Engineers, vol. 4, pp. 455–492. 1876.

Pennock, J. D. Laboratory note on the heat-conductivity, expansion, and fusibility of firebrick. Trans. Amer. Inst. Mining Engineers, vol. 26, pp. 263–269.

Percy, J. Magnesia crucibles and bricks. Metallurgy, vol. 1, pp. 134–137. 1875.

Vlasto, S. J. The magnesite industry. Engineering and Mining Journal, March 10, 1900.

Weiss, N. Magnesite in Hungary. Iron Age, Jan. 15, 1903, pp. 20–21.

Anon. Magnesite [and magnesia brick]. Mineral Industry, vol. 10, pp. 438–439. 1902.

Oxychloride Cements.

In 1853 the chemist Sorel discovered that zinc chloride, when mixed with zinc oxide, united with it to form a very hard cement. Later it was discovered that the same held true of a mixture of magnesium chloride and magnesia. The product in both cases is the same—an oxychloride of zinc or magnesium respectively. Chlorides and oxides of several other elements possess this same property, but it has been utilized commercially only in the cases of the zinc and magnesium compounds. Of these, zinc oxychloride is extensively used as a stopping by dentists. Magnesium oxychloride, called commonly Sorel cement or magnesia cement, has more important technical uses.

Sorel's magnesia cement is made by mixing calcined magnesia with a solution of magnesium chloride of 25° or 30° Baumé. If the magnesia has been prepared from magnesite, it usually contains a little residual carbon dioxide (CO_2), and though setting very rapidly and giving a very strong cement, cracks are apt to develop during setting. When made from magnesium chloride (see p. 158) the magnesia is free from carbon dioxide, and though it sets and hardens less rapidly, no cracks appear.

The commercial magnesium chloride used in the preparation of Sorel stone, etc., usually contains sulphuric acid. As this acid and its compounds spoil the appearance and the durability of the stone produced, it is eliminated from the magnesium chloride by treatment with barium hydrate or barium carbonate. In practice,* the magnesium chloride is dissolved in water to form a solution of 20° to 25° Baumé, and the barium hydrate or carbonate is added by degrees and carefully stirred until the precipitate of barium sulphate ceases to increase. The amount of reagent required is usually between 6 and 10 per cent of the weight of the magnesium chloride treated.

Magnesia cement is used very extensively † as a binder, in connection with briquetting, in the manufacture of artificial building-stones, tiles, grindstones, and emery- and polishing-wheels. Its binding quality is very considerable, and it is very plastic and cheap. A good mixture for this use consists of 25 parts of magnesium chloride (45 per cent solution), 25 parts magnesia (93 per cent MgO), and 50 parts water. About 5 lbs. of this mixture will serve to cement 95 parts of stone, emery, etc. The resulting blocks are very solid and harden thoroughly within a few hours.

Gillmore, in 1871, prepared a report on certain American patented products based upon Sorel cements. As this report is still the only complete discussion of the subject it is reprinted below, almost verbatim.

"The several steps in the process, beginning with the raw magnesite, are briefly as follows, viz.:

"*First.* The magnesite is burnt in ordinary lime-kilns, at a dark cherry-red heat, for about twenty-four hours. The result is protoxide of magnesium, which is next ground to fine powder between horizontal millstones, furnishing what the Union Stone Company style 'Union cement'.

"Magnesite has been procured from various localities. That from Greece, California, Maryland, and Pennsylvania contains about 95 per cent of carbonate of magnesia, the residue being mostly insoluble silicious matter. The burnt product is perfectly white. A magnesite is procured in Canada which contains from 60 to 85 per cent of car-

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* Journ. Soc. Chem. Industry, vol 21, p. 257. 1902.

† Schorr, R. The briquetting of minerals. Eng. and Mining Journal, vol. 74, p. 673. 1902.

bonate of magnesia. A variable percentage of iron in the residue gives the cement derived from this stone a reddish tint.

"*Second.* For making stone, the burnt and ground magnesite (oxide of magnesium) is mixed dry in the proper proportion with the material to be united; that is, with powdered marble, quartz, emery, silicious sand, soapstone, or with whatever substance forms the basis of the stone to be imitated or reproduced.

"The usual proportions are: for emery-wheels, 10 to 15 per cent of oxide of magnesium by weight; for building-blocks, such as sills, lintels, steps, etc., 6 to 10 per cent, and for common work for thick walls, less than 5 per cent.

"The dry ingredients are mixed together by hand or in a mill. A hollow cylinder revolving slowly about its axis would answer the purpose.

"*Third.* After this mixing they are moistened with chloride of magnesium, for which bittern water—the usual refuse of seaside saltworks—is a cheap and suitable substitute. The moistened material is then passed through a mill, which subjects it to a kind of trituration, by which each grain of sand or other solid material becomes entirely coated over with a thin film of the cement, formed by a combination of the chloride with the oxide of magnesium. The bittern water is required to be of the density of from 15° to 30° Baumé. The mass on emerging from the mill should be about as moist as molder's clay. The mixing-machine used by the Union Stone Company is an improved pug-mill invented by Mr. Josiah S. Elliott. It is represented as an excellent mill, doing its work thoroughly.

"*Fourth.* The mixture is formed into blocks by ramming or tamping it in strong molds of the required form, made of iron, wood, or plaster, precisely as described in paragraph 24, Report on Béton Aggloméré. The block may be taken out of the mold at once and nothing further need be done to it. The setting is progressive and simultaneous throughout the mass, as with other hydraulic cements, and requires from one hour to one day, depending somewhat on the chemical properties of the solid ingredients used, the carbonates as a rule requiring a longer time than the silicates.

"Building-blocks will bear handling, and may be used when three or four days old, although they do not attain their maximum strength and hardness for several months. Emery-wheels are not allowed to be used in less than four weeks.

"This stone so closely resembles the natural stone, whether marble, soapstone, sandstone, etc., from which the solid ingredients are obtained by crushing and grinding, that it is difficult, without the application of chemical tests, to detect any difference in either texture, color, or general lithological appearance.

"*Strength.*—In strength and hardness this stone greatly surpasses all other known artificial stones, and is equaled by few, if any, of the natural stones that are adapted to building purposes. The artificial marble takes a high degree of polish, being in this respect fully equal to the best Italian varieties.

"Some trials of 2-inch cubes at the Boston Navy-yard gave the following results, reduced to the crushing pressure upon one square inch:

No. 1,	crushing strength per square inch...............	7,187½ lbs.
No. 2,	" " " " "	11,562½ "
No. 3,	" " " " "	21,562½ "
No. 4,	" " " " "	7,343½ "

"In none of these samples did the proportion of the oxide of magnesium exceed 15 per cent by weight of the inert material cemented together. This statement is derived from the treasurer of the company.

"The principal business of the Union Stone Company up to the present time has been the manufacture of emery-wheels. The great tensile strength of the material may be inferred from the fact that in the proof trials the wheels are made to revolve with a velocity of from 2 to 3 miles per minute at the circumference. They do not usually begin to break until a velocity of from 4 to 5 miles per minute is attained.

"From a number of specimens of this stone furnished the writer by the treasurer of the company, who also gave their age and composition as reported below, comprising coarse and fine sandstone of various shades of color, hones, white and variegated marble, emery-wheels, billiard-balls, concrete building-blocks, etc., some small blocks were prepared and subjected to crushing with the results given in Table 68.

"*Durability.*—The proofs of the durability of the Union stone rests upon other evidence than that furnished by severe and prolonged climatic exposure. In Boston, however, building-blocks have resisted two winters, and at the present time appear to be, and doubtless are, harder and stronger than before they were touched with frost.

"Dr. C. T. Jackson, State Assayer of Massachusetts, reports upon it as follows:

"'I find that the frost test (saturated solution of sulphate of soda) has not the power of disintegrating it in the least. The trial was made by daily immersions of the stone in the sulphate-of-soda solution for a week and allowing the solution to penetrate the stone as much as pos-

TABLE 68.

COMPRESSIVE STRENGTH OF SOREL STONE.

Character of the Inert Materials.	Proportion by Weight of Oxide of Magnesium.	Age of Blocks.	Size of Blocks.	Total Crushing Strength.	Crushing Strength per Square Inch.
	Per Cent.			Lbs.	Lbs.
1. Coral sand.	12	1 year	2″ ×2⅛″×1⅞″	26,500	6,235
2. Pulverized quartz .	12 to 15	1 "	1⅜″×2″ ×1⅜″	20,000	7,272
3. Washed flour of emery (a piece of hone).	Not known	2 years	1⅜″×2″ ×1⅜″	54,000	19,636
4. Fine marble.	15	3 "	1½″×1½″×1½″	26,000	11,555
5. Mill-sweepings.	12 to 13	9 months	1⅞″×2″ ×1⅞″	23,000	6,133
6. Marble and sand. . .	12	2 years	1⅝″×2″ ×1½″	16,000	4,923
7. Marble with colored veneer.	Not known	Not known	1¼″×1¼″×1″	12,000	7,680

sible and then to crystallize. From this test it is evident that your stone will withstand the action of frost more perfectly than any sandstone or ordinary building stone now in use. I see no reason why it will not stand as well as granite.'

"A *perfect* resistance to the freezing and thawing of one winter may safely be accepted as conclusive evidence of the durability in the open air of an artificial stone of which the matrix is any kind of hydraulic cement. At no subsequent period will it be as likely to fail, from freezing and thawing, as during the first winter. A stone suitable for all kinds of building purposes on land might, however, fail under the solvent action of sea-water. On this head it can be said that magnesian compounds are understood to resist the immersion in the sea better than the compounds of alumina or lime.

"For these reasons this new stone has, with some exceptions, been limited in its application to articles of small bulk and great comparative value, for which other approved and less expensive artificial stone is either not suitable or of less practical value. Although for architectural ornaments of elaborate design it is perhaps less costly, even now, than granite or marble, it cannot hope to compete successfully for general adoption and use by engineers and architects with the béton aggloméré and the softer kinds of natural stone until the market price of the oxide of magnesium is greatly reduced. For the peculiar purposes to which it is adapted, it supplies what has heretofore been felt as a great want, and in this field, which is neither narrow nor unvaried, it has no prominent rival.

"The following formula has been found suitable for window-caps, sills, steps, etc. The quantities specified will make 1 cubic foot of stone.

100	pounds	of beach sand, cost $1.00 per ton at the works	$0.05
10	"	of comminuted marble, cost $5.00 per ton at the works	0.02½
10	"	of Union cement (oxide of magnesium)	0.50
10	"	of chloride of magnesium in solution, 20° Baumé	0.02
130	"	yielding 1 cubic foot of molded stone	$0.59½

"The labor, depending somewhat on the design as regards the degree and character of its ornamentation, will vary per cubic foot from 20 to 25 cents, making total cost of 1 cubic foot of finished building-block 79½ to 84½ cents. This price may be reduced 10 to 15 cents per cubic foot by incorporating large pebbles and small cobble-stones during the process of molding.

"For foundations and other plain, massive walls, the proportion of cement may be very considerably reduced and the quantity of cobble-stones increased."

References on oxychloride cements, Sorel stone, etc.

Ebel [Magnesia cement concrete for use in mines]. Zeits. angew. Chemie, vol. 15, p. 44. Abstract in Journ. Soc. Chem. Industry, vol. 21, p. 175. 1902.

Gillmore, Q. A. Practical treatise on Coignet-Béton and other artificial stone. 1871.

Luhmann, E. Magnesia cement. Chem. Zeitung, vol. 25, Report 345. Abstract in Journ. Soc. Chem. Industry, vol. 21, p. 118. 1902.

Preussner, L. Magnesia cement. Thonindustrie Zeitung, vol. 25, p. 2115. Abstract in Journ. Soc. Chem. Industry, vol. 21, p. 257. 1902.

Schorr, R. The briquetting of minerals. Engineering and Mining Journal, vol. 74, p. 673. Nov. 22, 1902.

PART IV. HYDRAULIC LIMES, SELENITIC LIME, AND GRAPPIER CEMENTS.

CHAPTER XIII.

THE THEORY OF HYDRAULIC LIMES.

Before taking up the manufacture and properties of the various closely allied products—hydraulic limes, selenitic limes, and grappier cements—which are to be discussed in this part of the volume, it seems desirable to devote some space to a consideration of the general principles on which the manufacture and use of these products are based.

The materials heretofore discussed in this volume—the plasters, common lime, magnesia, etc.—have been simple in both composition and action. With the hydraulic limes, however, we take up the first member of a great class of very complex products. All these products possess hydraulic properties. In composition, they further agree in that they all consist essentially of silica, alumina, and lime, with or without magnesia and iron oxide. This group of complex cementing materials includes the hydraulic limes, the natural cements, the Portland cements, and the puzzolan cements. These four classes are quite distinct commercially, but it is at times difficult to draw the dividing lines between the classes in words. Before defining the class of "hydraulic limes" it will therefore be well to explain the principal criterion which will be employed in drawing up that definition. This criterion is the "Cementation Index", a more satisfactory form of the older "hydraulic index".

The "Hydraulic Index".—In discussing the classification of cementing materials, in the introduction to this volume, the statement is made that the power of setting under water, possessed by the hydraulic limes and cements, is due to the formation of compounds of silica, alumina, and lime during the manufacture of the cementing materials in question. This being the case, it is a fair assumption * that the degree of hydraulic activity and the strength of any given cementing material will be related, in some way, to the proportions in which it contains these ingredients (silica, alumina, lime, etc.), and to the manner in which they are combined.

It is obvious that it would be of great value to both manufacturer and engineer if we could devise some method for *quantitatively* expressing this relation between the composition and the hydraulic value of any given sample of cementing material. Several methods of doing this have been suggested and used by various authorities.

Of these methods of expression, the one that has come into most general use is based upon the calculation of the " hydraulic index ". The " hydraulic index ", as usually defined, is the ratio between the percentage of silica plus alumina to the percentage of lime (CaO). A hydraulic lime, for example, such as that from Metz (Analysis No. 2, Table 74), containing 18.47 per cent silica, 5.73 per cent alumina, and 68.19 per cent lime would therefore have for its hydraulic index

$$\frac{18.47+5.73}{68.19}=\frac{24.20}{68.19}=0.355 \text{ (\textit{Hydraulic Index}).}$$

The " hydraulic index ", calculated in this manner, is then used as a basis for classifying cementing materials according to their hydraulic activity. The following grouping, which is substantially that given by Spalding,† is an example of this:

Hydraulic Index.	Product.
Less than 0.10......	Common lime, quicklime
0.10 to 0.20........	Feebly hydraulic limes
0.20 " 0.40........	Eminently hydraulic limes
0.40 " 0.60........	Portland cement (if burned at high temperature)
0.60 " 1.50........	Natural cements
1.50 " 3.00........	Weak natural cements
3.00..............	Puzzolanas, etc.

The " hydraulic index " calculated and used in this fashion is certainly better than nothing, but it possesses defects which render it valueless in dealing with certain classes of cements. These defects arise chiefly from the facts that in calculating the " hydraulic index " (1) no allowance is made for the action of either magnesia or iron oxide, and (2) the assumption is made that silica and alumina are quanti-

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* Strictly speaking, this statement is based on more than a mere assumption; but as a matter of convenience discussion of the reasons for it will be deferred to later chapters.

† Spalding, F. P. "Hydraulic Cement", pp. 8, 31, 38.

tatively interchangeable, i.e., that 10 per cent of silica will have exactly the same effect as 10 per cent of alumina.

These defects have led the writer to abandon the use of the "hydraulic index" and to substitute therefor the index described in the next section as the "Cementation Index".

The Cementation Index.—As explained and defined below, the Cementation Index is a natural outgrowth from the formula proposed by Newberry for proportioning Portland-cement mixtures. The index now proposed differs from that formula in assigning values for the magnesia and iron oxide contained in the cement or lime, a change which is necessary in order to adapt it for use with the magnesian natural cements and the puzzolan cements. The proposed index is:

$$\text{Cementation Index} = \frac{(2.8\times\text{percentage silica}) + (1.1\times\text{percentage alumina}) + (.7\times\text{percentage iron oxide})}{(\text{Percentage lime}) + (1.4\times\text{percentage magnesia})}.$$

Example.—As an example of the details of calculating the Cementation Index, the hydraulic lime of Metz, whose analysis is given as No. 2 of Table 74, will be used. The essential ingredients of this lime, as given in the quoted analysis, are:

Silica (SiO_2)	18.47
Alumina (Al_2O_3)	5.73
Iron oxide (Fe_2O_3)	3.29
Lime (CaO)	68.19
Magnesia (MgO)	2.66

Substituting these values in the formula

$$\text{Cementation Index} = \frac{2.8 \text{ percentage silica} + 1.1 \text{ percentage alumina} + .7 \text{ percentage iron oxide}}{\text{Percentage lime} + 1.4 \text{ percentage magnesia}},$$

we have

$$\begin{aligned}\text{Cementation Index} &= \frac{(2.8\times 18.47) + (1.1\times 5.73) + (.7\times 3.29)}{(68.19) + (1.4\times 2.66)}\\ &= \frac{51.716 + 6.303 + 2.303}{68.19 + 3.724}\\ &= \frac{60.322}{71.914}\\ &= .839.\end{aligned}$$

As will be seen later, this is a very typical value for the Cementation Index of a good hydraulic lime.

The use of the Cementation Index, as here stated, involves certain assumptions as to the constitution of hydraulic cementing materials. These are, in order of importance:

(1) That in hydraulic limes and cements the hydraulic activity is due to the formation during manufacture of certain compounds of lime and magnesia with silica, alumina, and iron.

(2) That the silica combines normally with the lime in such molecular proportions as to form the tricalcic silicate, $3CaO.SiO_2$.

(3) That the alumina combines with the lime as the dicalcic aluminate, $2CaO.Al_2O_3$.

(4) That magnesia is, molecule for molecule, equivalent to lime in its action.

(5) That iron oxide is, molecule for molecule, equivalent to alumina.

Of these five assumptions, the first is simply a general statement of conditions which are recognized by everybody as probably existing. The second assumption, likewise, is generally accepted, since it agrees with the views of both Le Chatelier and Newberry. The third, based on Newberry's experiments and confirmed by those of Richardson, is practically accepted by all American cement chemists, though not by those who follow Le Chatelier.

The fourth and fifth assumptions, however, are open to question, and the writer realizes that serious objections may be urged against them. But he also realizes that magnesia and iron must be accounted for in some way, that the assumptions above made are inherently probable, and that the resulting " Cementation Index " works out very well in practice. For the present, therefore, the " Cementation Index " will be accepted as a guide in discussing the composition and the characteristics of the hydraulic limes.

Use of the Cementation Index in classification.—The Cementation Index will be used in classifying the various hydraulic products, for it gives information of value concerning the properties of the various products. But it cannot be the sole basis for classification, because the properties of a hydraulic cementing material will be later seen to depend not only on its composition, but on the conditions of its manufacture. A material having a Cementation Index of 1.05 might be, for example, a hydraulic lime, a natural cement, or a cement of the Portland type, depending chiefly on the temperature at which the raw material was burned. In general, however, the possible variation is by no means so wide as this. A material with a Cementation Index of 0.40, for example, could under no possible temperature conditions yield anything but a somewhat weak hydraulic lime.

In later chapters, when the separate products are under discussion, their respective Cementation Indexes will be determined and stated. At present we are only concerned with determining the limiting values of this index for the hydraulic limes. As will be seen from following paragraphs, these limits are theoretically very wide, but in actual practice very narrow.

Definition of hydraulic limes.—The *hydraulic limes* include all those cementing materials (made by burning siliceous or argillaceous limestones) whose clinker after calcination contains so large a percentage of lime silicate (with or without lime aluminates and ferrites) as to give hydraulic properties to the product, but which at the same time contains normally so much free lime (CaO) that the mass of clinker will slake on the addition of water.

The commercial advantage of manufacturing a material of this kind is that, while the product has hydraulic properties, yet its clinker will slake and pulverize itself on the simple addition of water, thus avoiding the expensive mechanical grinding required by the clinker of natural and Portland cements.

The definition, therefore, requires that a material to be called a hydraulic lime must satisfy two conditions: (1) its clinker must contain enough free lime to slake with water, and (2) the resulting powder must be capable of setting or hardening under water. These two requisite conditions, in their turn, fix the limits of lime that the clinker may contain. The *minimum* amount of lime present is obviously determined by the consideration that, after burning, enough free lime (in addition to that combined with the silica, alumina, and iron) must be present in the clinker to reduce the entire mass to powder by the force of its own slaking. The *maximum* amount of lime, on the other hand, is determined by the commercial condition that no more free lime should be present than is absolutely necessary to accomplish this pulverization, for the free lime, whose slaking powders the mass, is by that same slaking made into an inert, or at least non-hydraulic, material.

The desired result—the formation of a clinker consisting largely of lime silicates, etc., but also containing sufficient free lime to slake readily—can be attained in two different ways, which yield products very different in quality. These two methods are:

(1) By the calcination, at a medium temperature, of a siliceous or argillaceous limestone having a Cementation Index lying between 0.30 and 1.10. Such a limestone will carry so high a percentage of calcium carbonate (relative to its content of silica, alumina, and iron oxide) as to leave, after *most* of its silica, etc., have been combined with lime,

sufficient free lime to slake the clinker. Hydraulic limes produced in this fashion are the *typical* hydraulic limes, and the following chapters will have reference to such materials only. It is possible, however, to produce a hydraulic lime by another method, as above noted. This second and much less satisfactory method is

(2) By the calcination, at temperatures too low to permit perfect combination of the silica, alumina, and iron oxide with the lime, of a siliceous or argillaceous limestone (less rich in lime than those employed in the first method) having a Cementation Index of 1.10 to 1.60 or over. In other words, a rock is used which would, under proper conditions of burning, give a good natural cement. If it is burned at too low a temperature to effect this, however, the result will be a hydraulic lime, for the clinker will consist partly of silicate and aluminate of lime, together with notable amounts of free lime, free silica, and free alumina. Hydraulic limes produced in this way necessarily carry a very large proportion of absolutely inert material. They are, in fact, simple imperfectly burned natural cements and will not be discussed further in this connection.

Reverting to the true hydraulic limes, it has been said above that their Cementation Index may range from 0.30 to 1.10; and it will be seen later that commercial hydraulic limes do occur with indexes as low as 0.331, while others are as high as 1.06.

There is, however, considerable reason for dividing the true hydraulic limes into two groups, the first or *eminently hydraulic limes* containing those products whose index lies between 0.70 and 1.10; while the second group, or *feebly hydraulic limes,* contains products whose Cementation Index ranges from 0.70 down as low as 0.30. Commercial as well as theoretical differences serve to separate the two groups, and for that reason they will be discussed in separate chapters. Curiously enough, each of the two classes has an attendant secondary product to be considered. The eminently hydraulic limes during their calcination produce a by-product (grappiers) which is usually marketed separately as a "*grappier cement*". The feebly hydraulic limes on the other hand are often treated with sulphuric acid in such a way as to develop new properties, and are then marketed as *selenitic limes.* In further discussion of the hydraulic limes, therefore, they will be treated as two groups in two separate chapters, covering respectively

Chapter XIV. Eminently Hydraulic Limes: Grappier Cements.
Chapter XV. Feebly Hydraulic Limes: Selenitic Limes.

CHAPTER XIV.

EMINENTLY HYDRAULIC LIMES: GRAPPIER CEMENTS.

THE hydraulic limes are usually, compared to Portland or good natural cements, only feebly hydraulic. This fact, taken in connection with the abundance of materials suitable for the manufacture of natural cements, has prevented the introduction of hydraulic-lime manufacture into the United States, though in Europe the industry is of considerable importance. No hydraulic lime is at present made in this country, nor is there any prospect that the industry will ever be taken up here. A considerable amount of hydraulic lime and grappier cement is, however, annually imported. This is brought about by the fact that these products, being low in iron and soluble salts, are light colored and do not stain masonry. There is thus a fair market for them for architectural rather than for engineering uses. A prominent brand of grappier cement much used in the United States as a " non-staining cement " is called Lafarge.

The manufacture and properties of the hydraulic limes and grappier cements will be discussed briefly. This discussion will be practically confined to the practice followed at Teil, France, where the largest and best-known plants are located.

Composition of the ideal hydraulic lime.—The clinker of an ideal hydraulic lime should, as may be deduced from the considerations set forth in the preceding chapter, satisfy two limiting conditions. On the one hand, it must contain sufficient free lime to disintegrate the entire mass of clinker by the force of its own slaking. On the other hand, no more free lime should be present than is absolutely necessary to effect this disintegration; and no uncombined silica or alumina should be present in the clinker. This ideal condition would be arrived at, according to Le Chatelier,* if we could obtain a clinker containing four equivalents of lime for one of silica. Three of the four equivalents of lime would be united with all the silica to form tricalcic silicate, while the fourth equivalent of lime would remain free, and would

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* Trans. Am. Inst. Min. Eng., vol. 22, p. 16.

be sufficient to accomplish the disintegration of the entire mass, through the force produced during its own slaking. Accepting this statement, we can calculate the percentages of the various constituents which should be present in an ideal hydraulic lime, both before and after slaking, and also the composition of the limestone necessary to give, in burning, this ideal product. The results of such a calculation are shown in the following table.

TABLE 69.

COMPOSITION OF IDEAL HYDRAULIC LIMESTONE AND HYDRAULIC LIME.

	Hydraulic Limestone Before Burning.	Hydraulic Lime.	
		Before Slaking.	After Slaking.
SiO_2	13.20	21.20	19.08
CaO.	86.8	78.80	70.92
CO_2		0.00	0.00
H_2O.	0.00	0.00	10.00
	100.00	100.00	100.00
Index. . . .	0.753	0.753	0.753

In actual practice, however, it is found that these theoretical compositions cannot be worked up to advantageously. If, for example, a limestone of the composition given above (SiO_2 13.2 per cent, $CaCO_3$ 86.8 per cent) is burned under the ordinary conditions of hydraulic-lime manufacture, it is found that all the silica does not combine with three fourths of the lime, as is required by the theory. What actually happens is that part of the silica will combine with part of the lime to form tricalcic silicate, thus leaving a certain amount of uncombined silica and entirely too much uncombined lime. Any increase in the uncombined lime beyond the amount necessary to cause the clinker to disintegrate by its slaking lessens the hydraulic value of the product.

It is therefore necessary, in practice, to modify the ideal compositions, these modifications being in the following directions:

(*a*) *Lower lime content.* The limestones in actual use, as shown by the analyses quoted in Tables 70 and 71, differ from the ideal hydraulic limestone in carrying from 70 to 80 per cent of lime carbonate in place of the 86.8 per cent of theory. This lowering in the original lime carbonate content of the limestones decreases the amount of uncombined lime in the product.

(*b*) *Presence of alumina and iron.* Even the best hydraulic limestones in actual use carry notable amounts of alumina and iron oxide.

These constituents act as fluxes, facilitating the combination of the silica and lime. They also combine themselves with lime to form aluminates and ferrites of lime. These latter salts do not increase the hydraulic value of the product, for they become hydrated and inert during the process of slaking, but their formation disposes of some of the excess of free lime.

The effect of these modifications is shown clearly when the Cementation Indexes of the ideal and the various commercial products are computed and compared. Le Chatelier's ideal lime has a Cementation Index of 0.75, while the actual limes whose analyses are given later will average about 0.85.

Analyses of a number of commercial hydraulic limes are given in Table 74, page 179.

Raw materials: hydraulic limestones.—The limestones actually used in the manufacture of hydraulic limes will carry from 70 to 80 per cent of lime carbonate. In hydraulic limestones of the best types, such as are used at Teil, France, the silica will vary between 13 and 17 per cent, while the alumina and iron together rarely exceed 3 per cent. Several analyses of hydraulic limestones are given in Tables 70 and 71.

TABLE 70.

ANALYSES OF HYDRAULIC LIMESTONES, TEIL, FRANCE.

	1.	2	3.	4.
Silica (SiO_2)	12.40	13.75	16.89	14.30
Alumina (Al_2O_3)	0.60	0.65	0.81	0.70
Iron oxide (Fe_2O_3)	0.50	trace	trace	0.80
Lime (CaO)	47.49	47.00	45.40	46.50
Magnesia (MgO)	n. d.	n. d.	n. d.	n. d.
Carbon dioxide (CO_2)	37.31	36.93	35.67	36.54

1. Alignole quarry; average of six analyses by Rivot.
2. Gaillant quarry; average of three analyses by Rivot.
3. Tinlière quarry; analysis by Rivot.
4. Lafarge quarry; average of nine analyses by Rivot.

TABLE 71.

ANALYSES OF HYDRAULIC-LIME ROCKS, FRANCE AND GERMANY.

	1.	2.	3.	4.
Silica (SiO_2)	17.00	11.60	11.03	11.20
Alumina (Al_2O_3)	1.00	3.60	3.75	5.30
Iron oxide (Fe_2O_3)	.....	3.0	5.07	4.60
Lime (CaO)	44.80	42.84	43.02	35.50
Magnesia (MgO)	0.71	1.43	1.34	5.85
Carbon dioxide (CO_2)	35.99	35.23	35.27	34.35

1. Senonches, France. Descotils, analyst.
2. Metz, Germany. Berthier, analyst.
3. Hausbergen, Germany. Muspratt, analyst.
4. Plassac, France. Vicat, analyst.

Quoted by Zwick, "Hydraulischer Kalk und Portland-Cement", pp. 66, 67.

TABLE 72.

ANALYSES OF THE VARIOUS BEDS IN THE HYDRAULIC LIMESTONE QUARRIES AT MALAIN, FRANCE.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
Silica (SiO_2)	7.60	10.15	10.30	12.30	15.70	13.80	14.20	14.25	14.70	14.75	16.35	16.10	16.80	14.90	14.35	12.45	14.85	6.40
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	0.75	0.90	0.65	1.00	1.10	0.80	0.85	0.75	0.60	1.05	1.00	0.80	0.30	0.80	0.80	0.70	0.75	0.45
Lime (CaO)	50.05	48.05	48.30	46.90	44.75	46.30	45.75	45.35	45.05	45.15	43.85	44.20	44.60	45.10	45.55	46.80	45.15	51.05
Magnesia (MgO)	0.30	0.30	0.30	0.25	0.20	0.25	0.40	0.40	0.30	0.15	0.55	0.40	0.40	0.45	0.40	0.45	0.45	0.45
Carbon dioxide (CO_2) Water	41.30	40.60	40.45	39.55	38.25	38.85	38.80	39.25	39.35	38.90	38.25	38.50	37.90	38.75	38.90	39.60	38.80	41.65
Cementation Index	.....	.....	0.739							.....	1.05							

Burning.—Hydraulic lime is burned in continuous kilns, like common lime. No difference, in fact, exists between the burning of common and of hydraulic limes, so far as the practical operations involved are concerned. The temperature attained in burning is, however, higher in hydraulic lime-kilns than in those burning common lime, and the fuel requirements are correspondingly increased. Beckwith states, for example, that at Teil 100 tons of coal are required to burn stone equivalent to 500 tons of screened lime. This corresponds to a fuel consumption of 20 per cent by weight on the lime production.

The temperature and thoroughness of the burning are directly related to the Cementation Index of the lime. The higher the index the less care will be necessary to avoid the presence of too much free lime. A hydraulic lime of index 0.75, for example, would be much more difficult to burn properly than one whose index ran as high as 0.85 or so. In fact, as the index approaches 1.00, the difficulty is, not to avoid free lime, but to keep enough free lime in the product to enable it to slake properly.

In Tables 73 and 74 are given the analyses of a number of hydraulic limes, after being burned but before slaking.

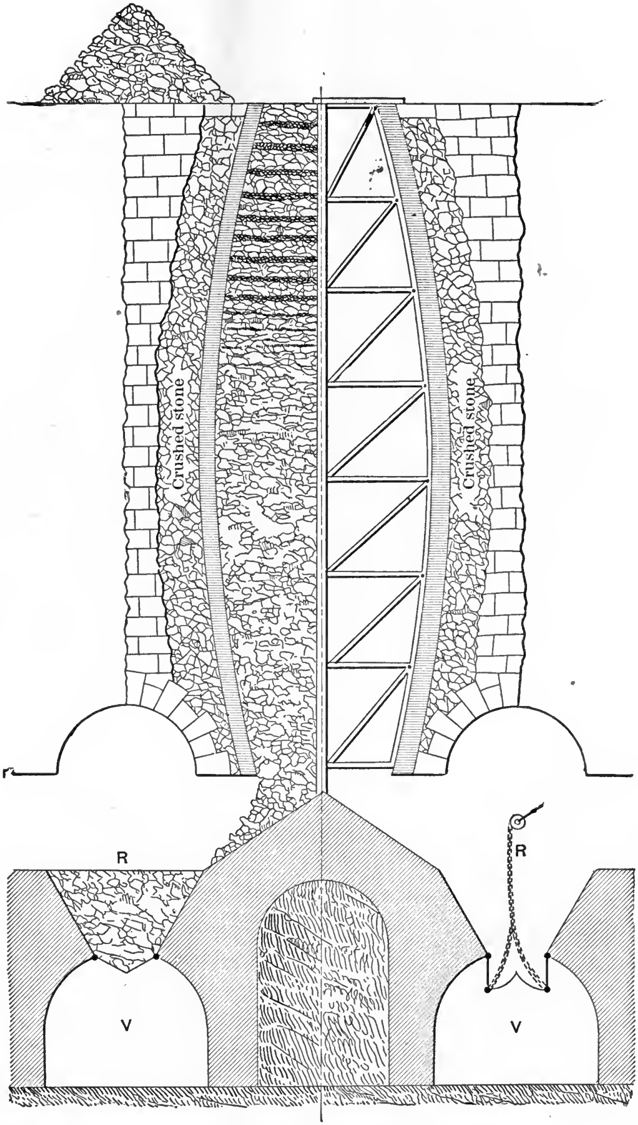

FIG. 27.—Kiln used for burning hydraulic lime, Malain, France. (After Bonnami.)

TABLE 73.

ANALYSES OF HYDRAULIC LIME BEFORE SLAKING (TEIL, FRANCE).

	1.	2.	3.	4.	5.	6.	7.	8.	9.
Silica (SiO_2)	20.33	22.39	23.60	22.95	20.57	21.7	26.07	26.4	22.59
Alumina (Al_2O_3)	1.00	1.06	1.28	1.12	1.13	1.8	4.38	3.0	2.63
Iron oxide (Fe_2O_3)	0.82	tr.	tr.	1.28	tr.	0.6	tr.		0.84
Lime (CaO)	77.87	76.55	75.12	74.64	77.76	74.0	68.94	65.16	65.62
Magnesia (MgO)	n. d.	n. d.	n. d.	n. d.	0.54	0.7	0.61	1.04	1.54
Cementation Index	.753	.834	.898	.899	.749	.842	1.115	1.155	.985

1. Average of lime burned from Alignole quarry rock.
2. " " " " " Gaillant " "
3. " " " " " Tinlière " "
4. " " " " " Lafarge " "

(1–4) Analyses by Rivot. Quoted by Zwick, "Hydraulischer Kalk und Portland-Cement", pp. 67, 69.

5. Analysis by Vicat. Quoted by Beckwith, "Hydraulic Lime of Teil", p. 13.
6. Quoted by Stanger and Blount, Mineral Industry, vol. 5, p. 70.
7. Analysis by Vicat. Quoted by Beckwith, "Hydraulic Lime of Teil", p. 13.
8. Analysis by Landrin. Quoted by Thorpe, "Dictionary Applied Chemistry", vol. 1, p. 483.
9. Analysis by Michäelis. Quoted by Schoch, "Mortel-Materialen", p. 73.

Two of the above analyses of Teil lime, Nos. 7 and 8, give exceptionally high values for the Cementation Index. The average index of all nine samples is 0.913; if Nos. 7 and 8 be excluded the average is 0.85.

TABLE 74.

ANALYSES OF HYDRAULIC LIMES, FRANCE, GERMANY, AND ENGLAND.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	26.77	18.47	17.18	17.75	23.61	24.33
Alumina (Al_2O_3)	1.57	5.73	5.84	8.88	3.89	3.73
Iron oxide (Fe_2O_3)	.....	3.29	6.32	6.18	.....	n. d.
Lime (CaO)	70.54	68.19	68.56	56.01	71.99	71.94
Magnesia (MgO)	1.12	2.66	2.09	9.28	0.51	n. d.
Cementation Index	1.06	.839	.839	.925	.968	1.00

1. Senonches, France. Descotils, analyst.
2. Metz, Germany. Berthier, analyst.
3. Hausbergen, Germany. Muspratt, analyst.
4. Plassac, France. Vicat, analyst.
5. d'Emondeville, France. Vicat, analyst.

(1–5) Quoted by Zwick, "Hydraulischer Kalk und Portland-Cement", pp. 66–67.

6. Lyme Regis, England. Quoted by Cummings, "American Cements", p. 35.

Slaking.—Hydraulic lime, after burning, is a mixture of two distinct compounds. Part of the mass is composed of lime silicate, which would not slake if water were poured on it, but would form a hydraulic cement if finely ground. The remainder of the hydraulic lime consists simply of quicklime, which *will* slake with water.

The result of the mixture of the two ingredients is that if water be poured on a lump of hydraulic lime the portion consisting of quicklime will rapidly take up the water and slake. In its slaking its expansion will break up the entire mass into a fine powder. If this operation be done carefully, with just the proper amount of water, the result will be a fine, dry, white powder, consisting mostly of lime silicate with about one third to one fourth as much of slaked lime.

In the earlier days of hydraulic-lime manufacture in France (and even at the present day in England) it was the practice to put the hydraulic lime on the market in lumps, just as it is drawn from the kiln, leaving the work of slaking it to the purchaser. At present, however, the slaking in the French works is done at the lime-plant. The advantages of this method of procedure are that (1) the slaking is done more uniformly and carefully, so that the value and reputation of the lime is improved, and (2) the lime gains considerably in weight and bulk during slaking, so that the cost of slaking is made up.

Slaking should be done with as little water as is compatible with thorough slaking. The lime as drawn from the kiln is therefore spread out in thin layers and lightly sprinkled with water. It is then shoveled up into heaps or into bins, where it is allowed to remain for ten days or so. The slaking is completed, while the lime is thus heaped up, by the aid of the steam which is generated.

After slaking is completed, the lime remains as a fine powder interspersed with lumps (grappiers) of harder material. These lumps consist in part of lime silicate and in part of unburned or underburned limestone. It would be desirable if practicable to remove the latter material, as it is, of course, valueless as a cement. The lumps of lime silicate, on the contrary, will, if finely ground, make a good natural cement. This separation is, however, commercially impracticable, and therefore all the grappiers are treated together.

The lime after slaking is passed over screens (of about 50-mesh). These screens permit all the slaked lime to pass, but reject the grappiers. The lime is sent to the packers, while the grappiers are ground finely under millstones. So far as can be learned, a certain percentage of ground grappiers is always added to the lime, in order to increase its hydraulicity. As later briefly noted (p. 185), the grappiers alone are also sold as a cement.

The analyses by Durand-Claye, given in Table 75, are quoted in Spalding's "Hydraulic Cements", p. 20, and serve to illustrate the composition of the various products.

In this series analysis No. 1 is of the lime which has completely powdered during slaking and passed through the first sieve, while analysis No. 3 is of the grappiers rejected by this sieve. It will be seen that while the slaked lime has a Cementation Index of 0.992, the grappiers are proportionately less rich in lime (CaO), having an index of 1.63. In order to increase the hydraulic properties of the lime which has passed the sieve, a certain proportion of ground grappiers is added to it. This causes the lime as marketed to have a Cementation Index

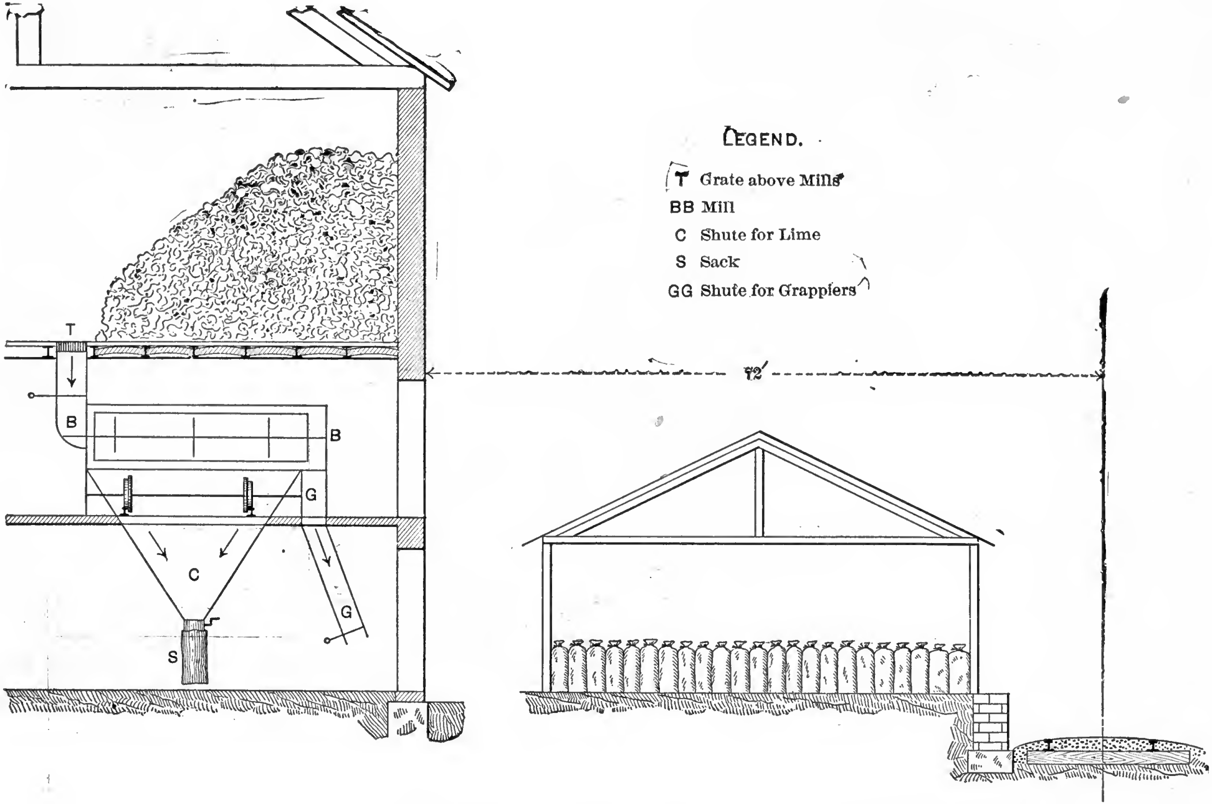

FIG. 28.—Section of hydraulic lime-plant at Malain, France. (After Bonnami.)

TABLE 75.

ANALYSES OF KILN PRODUCTS, TEIL, FRANCE.

	1.	2.	3.	4.
Silica (SiO_2)	23.05	23.95	31.85	43.90
Alumina (Al_2O_3)	2.75	3.10	4.25	8.20
Iron oxide (Fe_2O_3)				
Lime (CaO)	65.75	63.35	55.60	45.25
Magnesia (MgO)	1.50	1.15	1.20	0.85
Water, etc.	6.95	8.50	7.10	2.60
Cementation Index	0.992	1.08	1.63	2.82

of 1.08, as shown by analysis No. 2, which is of the Teil lime in its commercial form. During the burning a small percentage of a third compound close in composition to $CaO.SiO_2$ is formed. This product is not used in either the hydraulic-lime or grappier-cement industries, but is mixed with slaked lime and used in the manufacture of pipe, tile, etc. It is, in fact, an artificial puzzolana, as is seen from its analysis (No. 4), which gives a Cementation Index of 2.82.

These analyses by Durand-Claye have been used because they form a complete series. They are not entirely representative, however, of Teil hydraulic lime, as is seen on comparing them with analyses No. 2 and 3 in Table 76, below. These latter analyses give Cementation Indexes of 0.841 and 0.854 respectively, which are considerably lower than of the corresponding analyses of Table 75.

TABLE 76.

ANALYSES OF HYDRAULIC LIMES, AFTER SLAKING.

	1.	2.	3.
Silica (SiO_2)	22.0	19.05	18.2
Alumina (Al_2O_3)	2.0	1.6	1.2
Iron oxide (Fe_2O_3)	2.0	0.55	0.8
Lime (CaO)	62.0	65.10	60.0
Magnesia (MgO)	1.5	0.65	1.32
Sulphur trioxide (SO_3)	0.5	0.3	n. d.
Carbon dioxide (CO_2)	0.0	12.45	8.00
Water	10.0		n. d.
Cementation Index	1.016	0.841	0.854

1. Typical hydraulic lime, after slaking. Le Chatelier, Trans. Am. Inst. Min. Engrs., vol. 22, p. 16.
2. Hydraulic lime of Teil, after slaking. Thorpe, Dict. Applied Chem., vol. 1, p. 474.
3. Hydraulic lime of Teil, after slaking. Gillmore, "Limes, Cements, and Mortars", p. 125.

Weight and specific gravity.—Beckwith states that Teil lime in lumps, before slaking, weighs 36¼ lbs. per cubic foot; while slaked and screened its weight averages about 43 lbs. per cubic foot. According to Schoch,* the hydraulic limes average in specific gravity about 2.9

Tensile and compressive strength.—The results given in Table 77 are quoted by Schoch * as being fair averages for hydraulic-lime mortars composed of one part lime and three parts sand; kept for seventy-two hours after molding in a moist atmosphere and the remainder of the time under water.

TABLE 77.

AVERAGE STRENGTH OF HYDRAULIC LIMES. (SCHOCH.)

	Pounds per Square Inch.		
	7 Days.	28 Days.	1 Year.
Tension.	64 lbs.	100 lbs.	299 lbs.
Compression.	356 "	683 "	1920 "

These results may be compared with those given in Tables 78 and 79, which are quoted by Beckwith as the averages of several series of experiments carried on at Toulon and Marseilles on hydraulic-lime mortars composed of about one part lime to two parts of sand. These mortars were made into blocks and kept under salt water the entire time.

TABLE 78.

TENSILE STRENGTH OF TEIL HYDRAULIC-LIME MORTAR.

Time Immersed.	Tensile Strength in Pounds per Square Inch.						
	1.	2.	3.	4.	5.	6.	Average.
45 days.	31.71	40.38	30.79	30.83	. . . .	38.42	34.43
90 "	85.06	88.49	83.78	77.68	57.59	83.77	79.39
180 "	97.11	106.22	89.16	86.88	86.03	94.86	93.38
1 year.	123.43	111.63	126.42	122.15	121.30	120.94	120.95
2 years.	141.06	164.20	. . . .	. . . .	. . . .	. . . .	152.63

Ratio of compressive to tensile strength.—When in use, limes and cements are usually subjected to direct compressive stress only, tensile strains being rarely applied in well-designed and well-built structures. In testing, however, a test for tensile strength is much cheaper and more readily applied than one for compressive strength. The result is, that though limes and cements are almost entirely used in com-

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* Schoch, C. Die moderne Aufbereitung und Wertung der Mörtel-Materialen, p. 74.

TABLE 79.

COMPRESSIVE STRENGTH OF TEIL HYDRAULIC-LIME MORTARS.

Time Immersed.	Compressive Strength in Pounds per Square Inch.				
	1.	2.	3.	4.	Average.
45 days	219.59	191.75	194.09	205.04	202.62
90 "	359.62	362.41	355.20	259.15	334.10
180 "	593.98	467.13	451.34	504.24	504.17
1 year	612.91	591.84	561.87	588.99	588.90
2 years	613.88	577.33	573.92	....	588.38

pression, they are usually tested in tension. For this reason it is desirable to ascertain, as definitely as possible, the ratio which exists between the compressive and the tensile strength of any type of lime or cement. If this ratio be once determined, a *tensile* test can thereafter be used to determine the *compressive* strength of the material.

In the present case, the tensile and compressive tests given in Tables 77, 78, and 79 have been compared. The results are sufficiently close to indicate that the compressive strength of a hydraulic-lime mortar mixed in the usual working proportions (1 lime to 2 or 3 sand) will be from five to six times the tensile strength of the same mixture. (The actual average value, given by eight tests, for this ratio was 5.38 to 1.)

Proportions for mortars and concretes.—The following proportions for making mortars and concretes with hydraulic lime are recommended by Beckwith:

(*a*) Mortar for use in salt water: 10½ U. S. bushels (590 lbs.) of Teil lime to 1 cubic yard of sand, equivalent to one scant measure of lime to two full measures of sand.

(*b*) Mortar for use in fresh water: 9 U. S. bushels (506 lbs.) of Teil lime to 1 cubic yard of sand, equivalent to 1¼ measures of lime to 3 measures of sand.

(*c*) Mortar for use in air: 7½ U. S. bushels (421 lbs.) of Teil lime to 1 cubic yard of sand, equivalent to 1 measure of lime to 3 measures of sand.

(*d*) For concretes the usual proportions are:

  (1) For use in salt water, 2 measures mortar to 3 measures of broken stone.

  (2) For use in fresh water, 1 measure mortar to 2 measures of broken stone.

Grappier Cements.

Grappier cements are made by grinding finely the lumps of unburned and overburned material which remain when a hydraulic lime is slaked. These lumps, as earlier noted, consist partly of lime silicate and partly of unburned limestone. The value of the resulting grappier cement will depend on the proportions in which these two ingredients occur in the lumps. If lime silicate forms most of the lumps, the grappier cement will be a very satisfactory material, approximating to Portland cement in its properties. If most, or even a large part, of the lumps consist of unburned limestone, however, the grappier cement will be practically worthless.

Lafarge cement, well known on the American market as a "non-staining" cement, is a grappier cement of very satisfactory composition made at Teil, France.

Composition of grappier cements.

TABLE 80.

ANALYSES OF GRAPPIER CEMENTS.

	1.	2.	3.	4.	5.
Silica (SiO_2)	26.5	31.85	31.10	27.38	24.65
Alumina (Al_2O_3)	2.5	4.25	4.43	2.61	6.55
Iron oxide (Fe_2O_3)	1.5		2.15	1.02	2.60
Lime (CaO)	63.0	55.60	58.38	58.38	56.30
Magnesia (MgO)	1.0	1.20	1.09	0.46	0.90
Alkalies (K_2O,Na_2O)	n. d.	n. d.	0.94	n. d.	n. d.
Sulphur trioxide (SO_3)	0.5	n. d.	0.60	0.43	0.35
Carbon dioxide (CO_2)	5.0	7.10	1.28	n. d.	8.65
Water			n. d.	n. d.	
Cementation Index	1.212	1.63	1.560	1.359	1.356

1. Typical grappier cement. Le Chatelier, Trans. Amer. Inst. Min. Engrs., vol. 22, p. 19.
2. Teil grappiers. Analysis by Durand-Claye. Quoted by Spalding, "Hydraulic Cement", p. 20.
3. Lafarge cement. C. F. McKenna, analyst, 1897. Sales-agents' circular.
4. Lafarge cement. Quoted by E. Duryee, Engineering News, vol. 47, p. 23. Jan. 9, 1902.
5. Malain grappier cement. Quoted by Bonnami, "Fabrication et controle des Chaux Hydrauliques", p. 54.

Physical properties of grappier cements.—The only data available on the strength, etc., of grappier cements are those contained in the circular issued by the American sales-agents of the Lafarge brand. The tests were conducted in 1897 by Dr. C. F. McKenna.

The Lafarge cement gave the following results:

Specific gravity, not ignited	2.6	Initial set	4 hours
" " ignited	2.7	Final set	10 hours
Loss on ignition	3.83%	Fineness	99.8% through 50-mesh
		"	99.4% through 100- "

TABLE 81.

TESTS OF TENSILE STRENGTH, LAFARGE CEMENT. (MCKENNA.)

Composition of Mortar.	Tensile Strength in Pounds per Square Inch.						
	1 Week.	1 Month.	3 Months.	7 Months.	8 Months.	1 Year.	2 Years.
Neat cement, 22½% water.	330	465	500	...	...	...	665
Neat cement, 24% water.	320	...	...	542	...	645	665
1 part cement, 2 parts sand. ...	145	242	298	...	470		

These results have been plotted diagrammatically, as shown in Fig. 29.

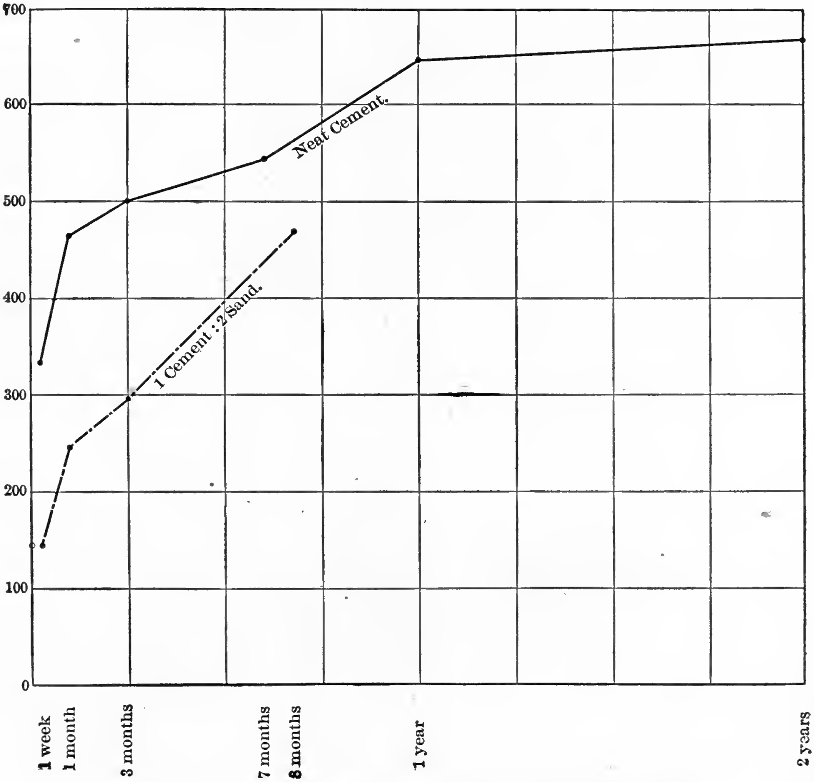

FIG. 29.—Tensile strength of Lafarge (grappier) cement.

CHAPTER XV.

FEEBLY HYDRAULIC LIMES: SELENITIC LIMES.

THE feebly hydraulic limes have been defined in Chapter XIII as including those products whose Cementation Index ranges between 0.30 and 0.70. This means that in such a product, no matter how high the burning temperature, not over 70 per cent of its total lime (CaO) *can* be in combination with the silica, etc., while if the Cementation Index, as shown by analysis, falls as low as 0.30, only 30 per cent of the total lime can be so combined, even under the most favorable circumstances. As combination can never be theoretically complete, it is safe to say that in the feebly hydraulic limes only from 20 to 60 per cent of their total lime is combined, the remainder being left free and capable of slaking. A product containing so much free lime and so little in the combined form can obviously possess little hydraulicity or strength.

Limes of this class would hardly merit description were it not for the fact that they are the usual type of *English* hydraulic limes, and that they often serve as a basis for making a product—selenitic lime—which requires brief attention.

TABLE 82.

ANALYSES OF HYDRAULIC-LIME ROCKS.

	1.	2.	3.
Silica (SiO_2)	5.00	4.64	7.40
Alumina (Al_2O_3)	4.23	7.08	2.70
Iron oxide (Fe_2O_3)		0.85	5.30
Lime (CaO)	48.65	48.27	40.82
Magnesia (MgO)	1.86	.....	4.52
Carbon dioxide	40.26	37.92	37.06
Cementation Index	0.356	0.443	0.581

1. Holywell, England. Muspratt, analyst.
2. Falhagen, Germany. Pasch, analyst.
3. Horb, Wurtemberg. Knauss, analyst.

TABLE 83.

ANALYSES OF FEEBLY HYDRAULIC LIMES.

	1.	2.	3.	4.	5.
Silica (SiO_2)	7.60	11.95	11.00	16.05	8.36
Alumina (Al_2O_3)	11.60	4.25	3.67	1.92	7.08
Iron oxide (Fe_2O_3)	0.96	8.52	3.00	3.22	
Lime (CaO)	79.09	65.73	78.40	77.29	81.44
Magnesia (MgO)	...	7.25	3.93	1.52	3.11
Cementation Index	0.439	0.581	0.440	0.621	0.331

1. Falhagen, Germany. Pasch, analyst.
2. Horb, Würtemberg. Knauss, analyst.
3. Fecamp, France. Rivot, analyst.
4. Aberthaw, England. Quoted by Cummings. "American Cements", p. 35.
5. Holywell, England. Muspratt, analyst.

Tensile strength.—In Table 84 are given the results of tests, on the tensile strength of various English hydraulic-lime mortars, carried out by Grant * about 1880. These tests were made on briquettes having a cross-section of $2\frac{1}{4}$ square inches; but the results given in Table 84 have been reduced so as to give the strength in pounds per square inch.

TABLE 84.

TENSILE STRENGTH OF HYDRAULIC-LIME MORTARS. (GRANT.)

Composition of Mortar.	1 Lime: 3 Sand.		1 Lime: 4 Sand.		1 Lime: 5 Sand.		1 Lime: 6 Sand.	
	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.
Lime A	50	68	44	57	30	45	21	28
Lime B	48	95	49	59	32	47	23	27
Lime C	40	81	26	61	21	44	18	34
Average	46	81	40	59	28	45	21	30

Each of the values given in this table represents the average of the results on five specimens tested. All the tests were made one year after the briquettes were molded. The words "wet" and "dry" refer to the fact that half of the briquettes were kept in air and the other half in water during the entire year.

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* Proc. Institution Civil Engineers, vol. 62, p. 165. 1880.

The results above tabulated are shown diagrammatically in Fig. 30. It will be noted that the "wet" briquettes gave results exceeding the "dry" in an average ratio of almost 1.6 to 1.

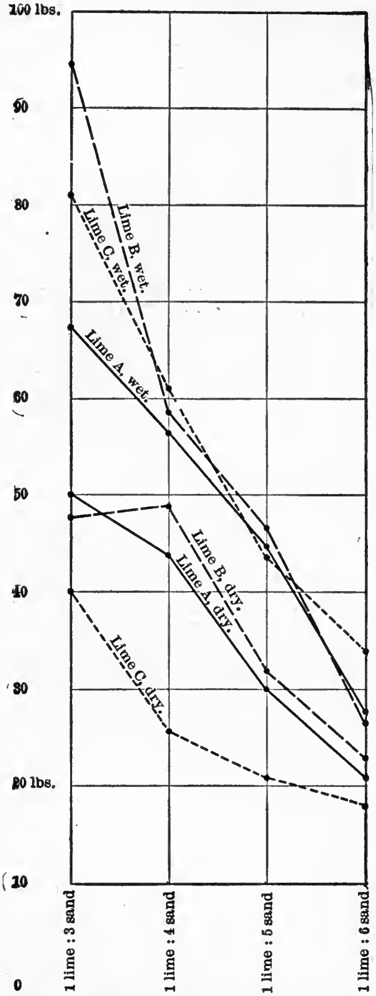

FIG. 30.—Tensile strength of feebly hydraulic limes.

Compressive strength.—Tests on the compressive strength of mortars made * from three English hydraulic limes are given in Table 85. These tests were made on 6-inch cubes kept in air for one year before testing.

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* Proc. Institution Civil Engineers, vol. 62, p. 165. 1880.

The results have been reduced to give the values for compressive strength in pounds per square inch.

TABLE 85.

COMPRESSIVE STRENGTH OF HYDRAULIC-LIME MORTARS. (GRANT.)

Composition of Mortar.	Kind of Lime.			
	Lime A.	Lime B.	Lime C.	Average.
	Pounds per Square Inch.	Pounds per Square Inch.	Pounds per Square Inch.	Pounds per Square Inch.
Lime 1, sand and gravel 6.	159	178	359	232
" 1, " " " 8.	72	172	167	137
" 1, " " " 10.	81	179	133	131

The values given are the average of ten specimens tested.

Selenitic Lime: Scott's Cement.

The cementing material known as Scott's cement, selenitic cement, or selenitic lime consists essentially of lime (CaO) plus a small percentage of sulphur trioxide (SO_3). The lime used as a basis for this cement is always a more or less hydraulic variety, while the sulphur trioxide may be added to it in the form of either plaster of Paris or sulphuric acid. The resulting selenitic lime or Scott's cement shows a markedly higher strength, both in compression and tension, than the lime from which it was made.

Manufacture of selenitic limes.—In his earlier patents Scott provided for the manufacture of this product by exposing lime to the fumes of burning sulphur. This was accomplished * "by reheating calcined lump lime in an oven having a perforated floor, beneath which were placed pots of burning sulphur. The sulphurous-acid fumes from the sulphur rose among the red-hot lumps of lime, leading to the formation of calcium sulphite ($CaSO_3$), and this in turn became oxidized into calcium sulphate ($CaSO_4$). The amount of sulphurous acid thus absorbed by the whole bulk of the lime was small, rarely exceeding from 2 to 3 per cent, and of course only the exterior surfaces of the lumps became coated with the sulphur compound; but when the cement was ground, to prepare it for use, the sulphate of lime became evenly distributed throughout the mass.

In course of time General Scott found that he could obtain the same results, either by adding sulphuric acid to the water used in preparing

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* Redgrave, G. R. Calcareous cements, p. 176. 1895.

the mortar or by the addition of powdered gypsum or plaster of Paris to the ground lime. It mattered little in what form the sulphuric acid was conveyed to the lime, and many soluble sulphates were found to answer quite as well as the sulphate of lime. Ultimately Scott specified the manufacture of a cement, which he named 'selenitic cement', by the addition of 5 per cent of ground plaster of Paris to calcined hydraulic lime, which was then ground to an impalpable powder and placed in sacks or casks for use".

The hydraulic lime used in the manufacture of selenitic lime is apparently always one of the feebly hydraulic varieties such as are discussed earlier in the present chapter.

Tensile strength of selenitic limes.—The following table shows the results of tests * by Grant about 1880 on various selenitic limes. For purposes of comparison tests are also given on two of the limes before the addition of sulphate. The tests were made on briquettes having a sectional area of 2¼ square inches; but in the table below the results given are reduced to pounds per square inch.

TABLE 86.

TENSILE STRENGTH OF SELENITIC LIMES. (GRANT.)

	1 Lime: 3 Sand.		1 Lime: 4 Sand.		1 Lime: 5 Sand.		1 Lime: 6 Sand.	
	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.	Dry.	Wet.
A. Gray lime, not selenitic.....	50	68	44	57	30	45	21	28
A′. " " selenitic.........	128	141	65	139	55	87	40	65
B. Lias lime, not selenitic.....	48	95	49	59	32	47	23	27
B′. " " selenitic.........	79	131	63	99	44	72	52	80
C. Selenitic lime.............	123	148	80	129	72	83	58	74
D. " " Rugby.......	91	151	59	102	33	77	29	66
E. " " Aberthaw....	128	204	83	147	71	123	..	76

Each of the above results represents the average of the tests of five specimens. The tests were made one year after the briquettes were molded. The words "wet" and "dry" refer to the fact that some of the briquettes were kept in air and others in water during the entire year. These results as to tensile strength are shown diagrammatically in Fig. 31.

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* Proc. Institution Civil Engineers, vol. 62, p. 165. 1880.

Compressive strength of selenitic limes.—A number of selenitic limes were tested for compressive strength by Grant, the results being given in Table 87.

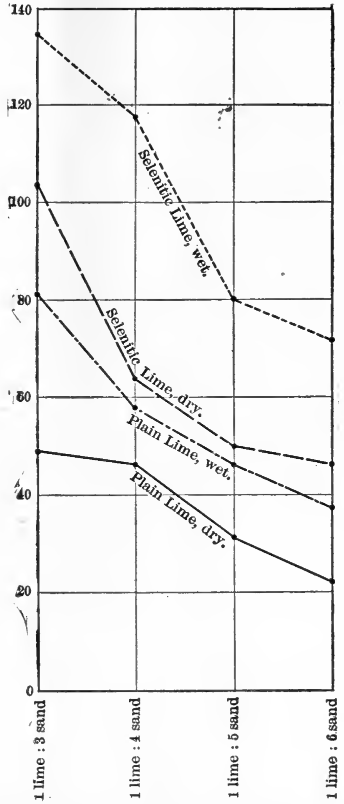


Fig. 31.—Tensile strength of plain hydraulic and selenitic limes.

TABLE 87.

COMPRESSIVE STRENGTH OF SELENITIC LIMES. (GRANT.)

	1 Lime: 6 Sand.	1 Lime: 8 Sand.	1 Lime: 10 Sand.
A. Gray lime, not selenitic	159	72	81
A′. " " selenitic	289	119	127
B. Lias lime, not selenitic	178	172	179
B′. " " selenitic	268	305	159
C. Selenitic lime	414	239	210
D. " " Rugby	577	533	329
E. " " Aberthaw	530	339	239

The samples discussed in the above table were made up into 6-inch cubes and kept in air one year before testing. The results in the table have been reduced to pounds per square inch.

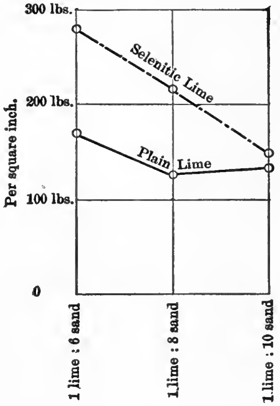


Fig. 32.—Compressive strength of plain hydraulic and selenitic limes.

The gain in strength due to this process of selenitizing is obvious, but it must be recollected that it gives satisfactory results only when employed on feebly hydraulic limes. With common non-hydraulic limes, and with the better grades of hydraulic limes, the results are not commensurate with the extra expense. For American use, therefore, Scott's process has little to commend it, for our good natural cements would leave little field for such a product as selenitic lime.

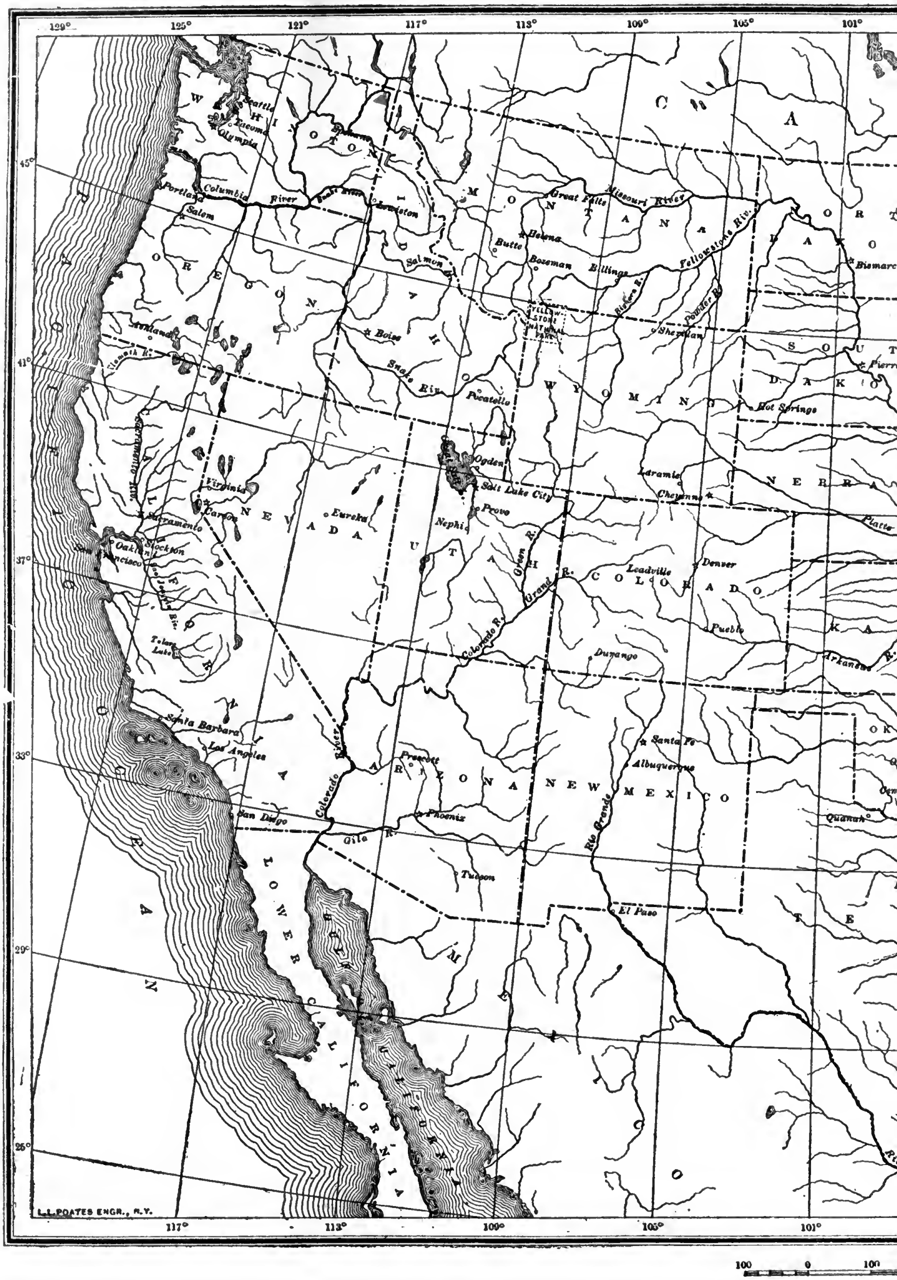
PART V. NATURAL CEMENTS.

CHAPTER XVI.

DEFINITION AND RELATIONS OF NATURAL CEMENTS.

Before taking up a detailed description of the materials, manufacture, and properties of natural cements it will be useful to make some brief general statements concerning the group. In the present chapter, therefore, an attempt will be made to discuss the natural cements as a class, laying emphasis upon the points of resemblance of the various brands and disregarding for a time their many points of difference.

The difficulties which are encountered in such an attempt are greater than the reader, at first sight, may imagine; for few engineers realize what a heterogeneous collection of products is included under the well-known name of " natural cement ". The cause of this lack of knowledge is not far to seek. Natural cements are too low in value to be shipped, under ordinary circumstances, far from their point of production. The natural cement made at any given locality has usually, therefore, a well-defined market area within which it is well known and subject to little competition. The engineer practicing within such an area naturally forms his idea of natural cements in general from what he knows of the brands encountered in his work, and as all the brands from one cement-producing locality are apt to resemble one another quite closely, he is likely to conclude that natural cements are quite a homogeneous class, with many points of resemblance and few of difference. The truth is, on the contrary, that there may be far greater differences in strength, rate of set, chemical composition, etc., between the natural cements made in two different localities than between any given brand of natural cement and a Portland cement. This will be brought out clearly in a later chapter, where the compo-



129°
125°
121°
117°
113°
109°
105°
101°
45°
41°
37°
33°
29°
25°
C A
WASHINGTON
Seattle
Tacoma
Olympia
Columbia River
Snake River
Lewiston
Portland
Salem
OREGON
Ashland
Klamath R.
IDAHO
Boise
Salmon R.
Snake Riv.
Pocatello
MONTANA
Great Falls
Missouri River
Helena
Butte
Bozeman
Billings
Yellowstone Riv.
Bighorn R.
Powder R.
Sheridan
YELLOWSTONE NATIONAL PARK
WYOMING
Laramie
Cheyenne
NORTH DAKOTA
Bismarck
SOUTH DAKOTA
Pierre
Hot Springs
NEBRASKA
Platte
PACIFIC OCEAN
CALIFORNIA
Sacramento Riv.
Sacramento
Stockton
Oakland
San Francisco
San Joaquin Riv.
Tulare Lake
Santa Barbara
Los Angeles
San Diego
NEVADA
Virginia
Carson
Eureka
UTAH
Great Salt Lake
Ogden
Salt Lake City
Provo
Nephi
Green R.
Grand R.
Colorado R.
COLORADO
Leadville
Denver
Pueblo
Durango
KANSAS
Arkansas R.
OKLAHOMA
Quanah
ARIZONA
Prescott
Phoenix
Tucson
Gila R.
Colorado River
NEW MEXICO
Santa Fe
Albuquerque
Rio Grande
El Paso
TEXAS
LOWER CALIFORNIA
GULF OF CALIFORNIA
MEXICO
L.L.POATES ENGR., N.Y.
117°
113°
109°
105°
101°
100
0
100

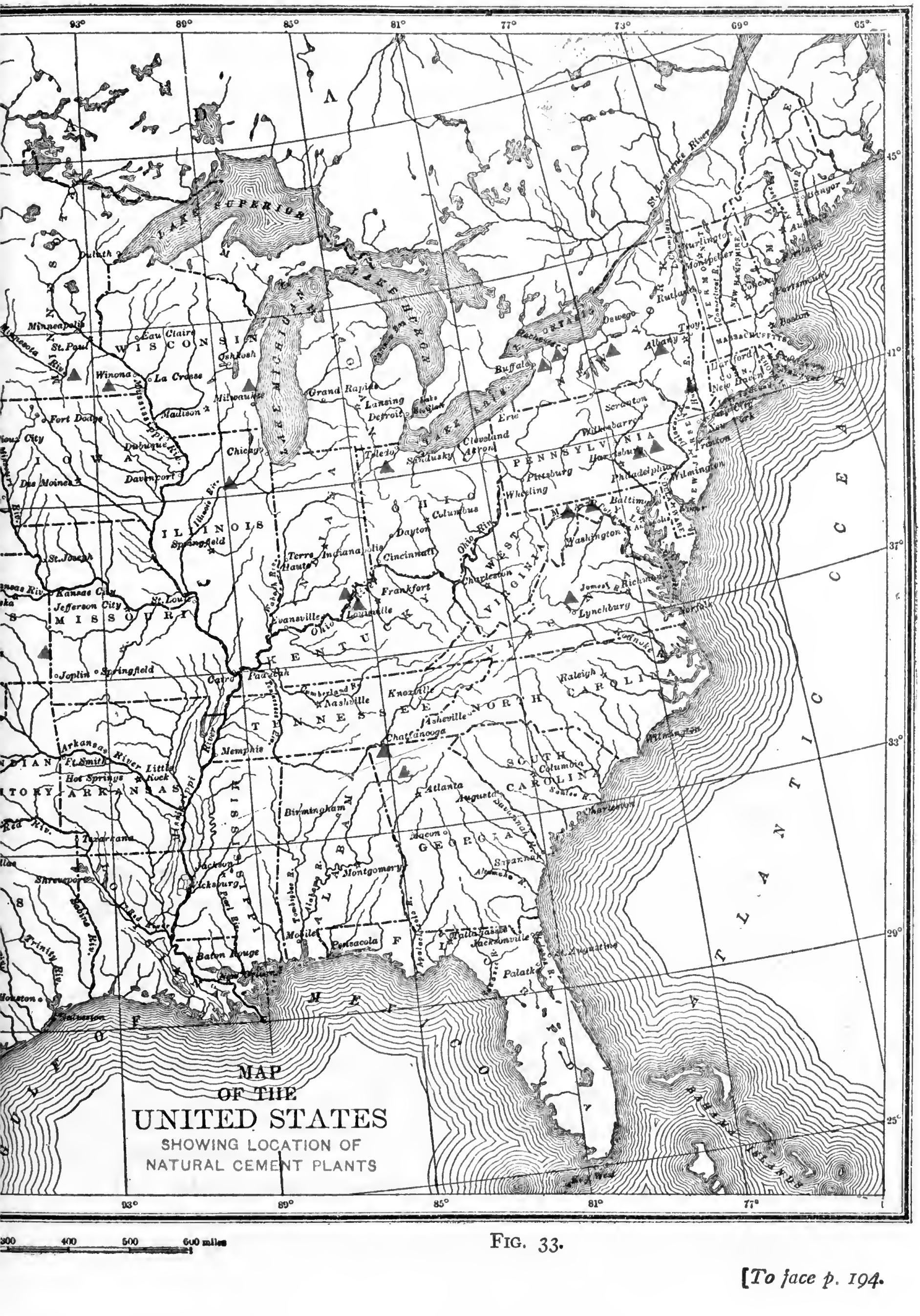


FIG. 33.

[*To face p. 194.*

sition and properties of the various natural cements will be discussed in considerable detail.

In the present volume the term "natural cements" will be used to include all those cements which are produced by burning, without previous mixing or grinding, a naturally impure limestone rock, i.e., a clayey or argillaceous limestone. As so used the term will include the class of doubtful products commonly known as "natural Portland cements", a class which is quite largely manufactured in Belgium and France. The reasons for including these "natural Portlands" with the natural cements instead of with the true Portlands are stated in detail in a later section of this volume.

The definition of natural cements given on a previous page can be restated here to advantage.

Definition.—Natural cements are produced by burning a natural clayey limestone containing 15 to 40 per cent of silica, alumina, and iron oxide without preliminary mixing and grinding. This burning takes place at a temperature that is usually little, if any, above that of an ordinary lime-kiln. During the burning the carbon dioxide of the limestone is almost entirely driven off, and the lime combines with the silica, alumina, and iron oxide, forming a mass containing silicates, aluminates, and ferrites of lime. In case the original limestone contained any magnesium carbonate the burned rock will contain a corresponding amount of magnesian compounds.

After burning, the burned mass will not slake if water be poured on it. It is necessary, therefore, to grind it quite fine, after which, if the resulting powder (natural cement) be mixed with water, it will harden rapidly. This hardening, or setting, will take place either in air or under water.

Relations of natural cements to others.—Natural cements differ from ordinary limes in two very noticeable ways. These are:

(1) The burned mass does not slake when water is poured on it.

(2) After grinding, natural-cement powder has hydraulic properties, i.e., if properly prepared it will set under water.

Natural cements are quite closely related to both hydraulic limes, on the one hand, and Portland cement, on the other, agreeing with both in the possession of hydraulic properties. They differ from hydraulic limes, however, in that the burned natural-cement rock will not slake when water is poured on it.

The natural cements differ from Portland cements in the following important particulars:

(1) Natural cements are not made by burning carefully prepared

and finely ground artificial mixtures, but by burning masses of natural rock.

(2) Natural cements, after burning and grinding, are usually yellow to brown in color and light in weight, their specific gravity being about 2.7 to 3.10, while Portland cement is commonly blue to gray in color and heavier, its specific gravity ranging from 3.0 to 3.2.

(3) Natural cements are always burned at a lower temperature than Portland, and commonly at a *much* lower temperature, the mass of rock in the kiln rarely being heated high enough to even approach the fusing- or clinkering-point.

(4) In use natural cements set more rapidly than Portland cement, but do not attain such a high ultimate strength.

(5) In composition, while Portland cement is a definite product whose percentages of lime, silica, alumina, and iron oxide vary only between narrow limits, various brands of natural cements will show very great differences in composition; while even the same brand, analyzed at different times, will show considerable differences in composition, due to variations in the natural limestones used.

Cementation Index.—In discussing the hydraulic limes (Chapter XIII) attention was called to the desirability of devising some method of general applicability for comparing the hydraulic activity of various cementing materials. The defects of the old "hydraulic index" were pointed out, and a new and more satisfactory index—the Cementation Index—was suggested as a substitute. The value of this innovation will appear in the present section, for in dealing with the natural cements such great variations in composition are found that it is absolutely necessary to have some means of comparing such different products.

The Cementation Index of any limestone or cement is found by applying the following formula:

$$\text{Cementation Index} = \frac{\begin{array}{c}(2.8\times\text{percentage silica}) +\\ (1.1\times\text{percentage alumina}) +\\ (.7\times\text{percentage iron oxide})\end{array}}{(\text{Percentage lime}) + (1.4\times\text{percentage magnesia})}.$$

When this formula is applied to an unburned limestone it must be recollected that the percentages used in the divisor are those of lime (CaO) and magnesia (MgO) respectively, *not* those of lime carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$).

Example of calculation.—The methods of calculating the Cementation Index of any product may be shown by an example, the Utica natural cement whose analysis appears as No. 1, Table 110, p. 253, being selected for this purpose. The five essential ingredients of that cement, as shown by the analysis, are:

Silica (SiO_2)	19.89
Alumina (Al_2O_3)	11.61
Iron oxide (Fe_2O_3)	1.35
Lime (CaO)	29.51
Magnesia (MgO)	20.38

These values are substituted in the following formula:

$$\text{Cementation Index} = \frac{\begin{array}{c}(2.8 \times \text{percentage silica}) + \\ (1.1 \times \text{percentage alumina}) + \\ (.7 \times \text{percentage iron oxide})\end{array}}{(\text{Percentage lime}) + (1.4 \times \text{percentage magnesia})}$$

$$= \frac{(2.8 \times 19.89) + (1.1 \times 11.61) + (.7 \times 1.35)}{(29.51) + (1.4 \times 20.38)}$$

$$= \frac{55.692 + 12.771 + 0.945}{29.51 + 28.532}$$

$$= \frac{69.408}{58.042}$$

$$= 1.19.$$

As will be later seen, this value is fairly characteristic for many natural cements.

Basal assumptions.—It has previously been stated (pp. 170, 171) that the applicability of the Cementation Index depends upon the fact that it is the exact equivalent *in percentages* of a formula which involves the following assumptions:

(1) That the hydraulic activity of any material depends on the formation of certain compounds of lime and magnesia with silica, alumina, and iron oxide.

(2) That in a hydraulic cement, lime combines with silica in such proportions as to form the tricalcic silicate ($= 3CaO.SiO_2$); while it combines with alumina in such proportions as to form the dicalcic aluminate ($2CaO.SiO_2$).

(3) That in a lightly burned natural cement at least magnesia may be regarded as *molecularly* interchangeable with lime, though of course the differences in their combining weights must be allowed for when the calculation is based on *percentages*.

(4) That iron oxide may, in similar fashion, be regarded as molecularly interchangeable with alumina.

Of these assumptions, the third and fourth may be questioned by other investigators, but it will be seen later that the hydraulicity of certain well-known products cannot be explained satisfactorily without taking account of the magnesia and iron oxide they contain.

Use of the Cementation Index.—If the assumptions on which the Cementation Index is founded are well based, it is evident that the hydraulic properties—or, rather, the hydraulic *possibilities*—of a product are indicated by its index. A product whose index falls below 1.00 must necessarily contain free lime or free magnesia, whatever the temperature at which it is burned, and such a product should therefore be strictly classed with the hydraulic limes, which require slaking before use. It will be seen later, however, that if a product contains much magnesia (say 20 per cent MgO or over) its Cementation Index may fall below 1.00 without demonstrable defects in the cement. This point is taken up on later pages in discussing the actual composition of various natural cements. A product with an index exceeding 1.00 *can* be burned so as to give complete combination of all its lime and magnesia, leaving none free. As the index increases, the temperature necessary to attain such complete combination decreases, but the hydraulic activity of the product also decreases, until an index exceeding 2.00 indicates a very lightly burned, but also very feeble, cement.

Cementation Index of natural cements.—The term "natural cement" as used in this volume will cover a very large class of cementing products. In the United States the name has become fairly well fixed in use, so that there need be little misunderstanding concerning the limits of the groups. In English and European practice, however, the term "natural cement" has never come into extensive use. It may therefore be necessary to state that, as above defined, it includes the lightly burned but often high-limed cements known to the European trade as "Roman cements", "quick-setting cements", etc., as well as the so-called "natural Portlands".

The differences in composition between the various cements included in this heterogeneous class naturally give rise to corresponding differences in their cementation index. It may be said for the group taken as a whole that the Cementation Index of natural cements varies between the limits of 1.00 and 2.00, falling below 1.00 only in the case of certain highly magnesian cements, and that *most* of the natural cements will fall between the narrower limits of about 1.15 to 1.60.

This variation of the Cementation Index may be used as a convenient basis for subdividing the "natural cements" into smaller groups of more homogeneous character.

A. Cements with an index between 1.00 and 1.15. These products when burned at sufficiently high temperature are rather slow-setting and high in tensile strength, including the "natural Portlands" and allied products. If not burned high enough, however, cements of such low index will necessarily contain large amounts of free lime and magnesia.

B. Cements with an index between 1.15 and 1.60. These include most American natural cements. As the index is higher than in Class A, it is not necessary to burn these products at so high a temperature. Practically all of the European "Roman" cements will also fall in this subgroup.

C. Cements with an index exceeding 1.60. These include the relatively low-limed natural cements, which carry so much clayey material that only a light burning is required in order to combine all their lime and magnesia. As the index rises above 2.00, the products become feebler in hydraulic properties, until at about 3.00 they can be considered only as artificial pozzuolanas.

CHAPTER XVII.

RAW MATERIAL: NATURAL-CEMENT ROCK.

Composition of natural-cement rock.—The raw material utilized for natural-cement manufacture is invariably a clayey limestone carrying from 13 to 35 per cent of clayey material, of which 10 to 22 per cent or so is silica, while alumina and iron oxide together may vary from 4 to 16 per cent. It is the presence of these clayey materials which give the resulting cement its hydraulic properties. Stress is often carelessly or ignorantly laid on the fact that many of our best-known natural cements carry large percentages of magnesia, but it should at this date be realized that magnesia (*in natural cements at least*) may be regarded as being almost exactly interchangeable with lime, so far as the hydraulic properties of the product are concerned. The presence of magnesium carbonate in a natural-cement rock is then merely incidental, while the silica, alumina, and iron oxide are essential. The 25 per cent or so of magnesium carbonate which occurs in the cement rock of the Rosendale district, New York, could be replaced by an equivalent amount of lime carbonate, and the burnt stone would still give a hydraulic product. If, however, the clayey portion (silica, alumina, and iron oxide) of the Rosendale rock could be removed leaving only the magnesium and lime carbonates, the rock would lose all of its hydraulic properties and would yield on burning simply a magnesian lime.

This point has been emphasized because many writers on the subject have either explicitly stated or implied that it is the magnesium carbonate of the Rosendale, Akron, Louisville, Utica, and Milwaukee rocks that causes them to yield a natural cement on burning. Even a casual consideration of the subject should have recalled to mind the fact that the Cumberland and Lehigh natural-cement rocks are practically free from magnesium carbonate.

A limestone containing sufficient argillaceous matter to make a good natural cement can generally be recognized by the characteristic clayey odor given forth when breathed on.

In determining in advance of actual calcination whether or not a given rock will make a good natural cement the Cementation Index will prove of service. This can be calculated, as explained on page 196, from the analysis of the rock. If the value of the Cementation Index is over 2.00, the rock will make only a very weak sort of cement, not worth putting on the market as a new product in face of competition from older and stronger brands. If, on the other hand, the Cementation Index is less than 1.00, the rock is in most cases unavailable, for after burning it will contain too much free lime and free magnesia to furnish a safe cement. As noted earlier, however, a rock whose index falls between 0.80 and 1.00 can be made into an apparently safe cement *if it contains 20 per cent or more of magnesia*, by burning at a very high temperature. If the Cementation Index falls between 1.00 and 2.00 it can be assumed that a natural cement of good quality *can* be made from the rock under proper conditions of burning, etc. Within these limits the properties of the cement will vary with the index. A rock with an index of 1.00 to 1.10, for example, will require burning at high temperature, especially if much lime be present (i.e., over 50 per cent CaO). As the index rises, the temperature necessary for burning decreases.

American Natural-cement Rocks.

In the following pages analyses of the rocks used at almost all of the natural-cement plants of the United States will be given. Notes on the physical character, geology, and other features of these rocks will also be presented.

Clayey limestones of the composition required for natural-cement manufacture are very widely distributed, both geologically and geographically, in the United States. There is hardly a State, in fact, in which natural cement of more or less value has not been made at one time or another. In order, however, that a natural-cement industry can become well established in any given locality, certain things are requisite in addition to the occurrence of a good natural-cement rock.

The rock must not only be of the right composition to make a good, sound, and strong cement, but it must be fairly steady in composition, and the beds must be located favorably for cheap extraction of the rock, either by quarrying or by mining. Fuel must also be obtainable at reasonable rates. A good local market and cheap transportation to outside points are necessities.

Of the many localities in the United States at which deposits of good natural-cement rock occur, so few possess the commercial advantages mentioned above that the important natural-cement-producing districts are correspondingly few. According to the United States Geological Survey Report for 1903 there were 65 natural-cement plants then in operation. Of these 20 were in New York State, 15 in the Louisville district of Indiana and Kentucky, 7 in the Lehigh district of Pennsylvania, 4 in Maryland, 3 in the Utica district of Illinois, 2 each in Georgia, Kansas, Minnesota, Ohio, Texas, Virginia, and Wisconsin, and 1 each in North Dakota and West Virginia. This suffices to show the extent to which the American natural-cement industry has become concentrated in certain favorable localities.

Georgia.—Two natural-cement plants are located in northwest Georgia, but they use cement rocks from two different geological formations, and their raw materials and products differ widely in composition.

The plant of the Chickamauga Cement Company is located at Rossville, Ga., a few miles south of Chattanooga. The raw material used is a thin-bedded slaty limestone of Chickamauga (Ordovician) age, which is here exposed over a considerable area. In geologic age, as well as in chemical composition, this rock is quite similar to the cement rock of the Lehigh district of Pennsylvania, but the Georgia deposit is not so thick as in that region. These shaly limestones outcrop at many points in northwest Georgia and northern Alabama, but so far have been utilized for natural cement only at the Rossville plant.

The second plant, that of the Howard Hydraulic Cement Company, is working on limestones of quite different character.

The Conasauga formation of the Cambrian is described by Dr. C. W. Hayes as being "normally composed—at the base of thin limestones interbedded with shales, then of yellowish or greenish clay shales, and at the top of calcareous shales, grading into blue seamy limestones".

The Western and Atlantic Railroad, now operated under lease by the Nashville, Chattanooga and St. Louis System, crosses the outcrop of these rocks from above Adairsville to within a mile of Kingston. At one point near the southern end of this belt limestone obtained from beds lying near the top of the Conasauga formation has long been utilized in the manufacture of natural cement at the plant of the Howard Hydraulic Cement Company, at Cement, Bartow County, Ga., about two miles north of Kingston.

In the low ridge east of the railroad at Cement station a section of these Conasauga limestones has been measured by Spencer.*

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* The Paleozoic group of Georgia, p. 100.

The series shown, from the top down, was as follows:

	Feet.
Blue limestone	8
Slaty limestone (cement rock)	4
Blue limestone	6
* Argillaceous limestone	2
* Siliceous limestone (hydraulic)	4
* Siliceous limestone (cement rock)	7
Fine black limestone	12
Earthy limestone	3
Shales	

When the plant was visited by the writer, in the fall of 1902, the three beds marked with asterisks (*) were being worked for natural cement. Spencer quotes the following analyses, made by W. J. Land:

	(1)	(2)
Silica (SiO_2)	22.10	10.00
Alumina (Al_2O_3)	5.45	6.10
Iron oxide (Fe_2O_3)	1.80	2.00
Lime (CaO)	24.36	30.80
Magnesia (MgO)	12.38	12.42
Carbon dioxide (CO_2)	32.76	37.88
Organic matter	0.15	0.50
Water	1.00	0.30
Cementation Index	1.69	0.749

Of these analyses, No. 1 probably represents the composition of the 7-foot bed of cement rock noted in Spencer's section, while No. 2 is probably from the 4-foot bed of hydraulic limestone immediately overlying this. As these beds are both worked for cement, the index of the product lies between those of the two rocks.

Illinois.—Three natural-cement plants operated by two companies are now working in Illinois, all of them being located near Utica, La Salle County. The rock used is a limestone belonging to the so-called "Lower Magnesian" group of early Western geologists. It is of Ordovician age and underlies the St. Peter's sandstone.

The section exposed in the neighborhood of the Utica cement-plants is as follows from the top downward:

	Thickness.
Cement rock	7 feet
Limestone	16–22 "
Cement rock	6 "
Sandstone	2–4 "
Cement rock	5 "

Of the three cement-rock beds shown in this section, the uppermost bed gives a very quick-setting cement, while the two lower beds furnish products of much slower set.

TABLE 88.

ANALYSES OF NATURAL-CEMENT ROCK, UTICA, ILLINOIS.

	1.	2.	3.	4.	5.
Silica (SiO_2)	12.22	17.01	21.00	21.12	14.15
Alumina (Al_2O_3)	9.39	3.35			6.37
Iron oxide (Fe_2O_3)	3.90	2.39	2.00	1.12	2.35
Lime (CaO)	24.40	32.85	24.36	23.66	26.32
Magnesia (MgO)	10.43	8.45	14.31	15.22	12.10
Alkalies (K_2O,Na_2O)	n. d.	n. d.	0.18	n. d.	0.18*
Sulphur trioxide (SO_3)	n. d.	1.81	n. d.	n. d.	1.81
Carbon dioxide (CO_2)	38.48	34.12	34.90	35.35	34.70
Water			3.00	1.07	2.03
Cementation Index	1.21	1.19	....	....	1.11

* Far too low: true value is probably over 4 per cent.

1. F. W. Clarke, analyst. Sample collected by E. C. Eckel.
2. C. Richardson, analyst. Brickbuilder, vol. 6, p. 151. July, 1897.
3. Blaney & Mariner, analysts. "Geology of Illinois", vol. 1, p. 151.
4. Blaney, analyst. Trans. Am. Inst. Min. Engrs., vol. 13, p. 180.
5. Average of preceding four analyses.

Indiana-Kentucky.—The plants of the "Louisville district" are mostly located in Indiana, though one or two mills are in operation on the Kentucky side of the Ohio River. The rock is a fine-grained clayey limestone of Devonian age. In color it varies from light drab to dark or bluish drab when fresh, weathering to a dull buff on long exposure. The cement-bed varies from 10 to 16 feet in thickness in the different quarries. As shown by the calculated values of the Cementation Index, the rock varies greatly in composition.

TABLE 89.

ANALYSES OF NATURAL-CEMENT ROCK, LOUISVILLE DISTRICT, IND.-KY.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	9.69	9.80	13.65	15.21	18.33	13.36
Alumina (Al_2O_3)	2.77	2.03	3.46	4.07	4.98	3.46
Iron oxide (Fe_2O_3)	1.95	1.40	1.45	1.44	1.67	1.58
Lime (CaO)	29.09	29.40	34.55	33.99	30.41	31.49
Magnesia (MgO)	15.69	16.70	7.97	7.57	8.04	11.19
Carbon dioxide (CO_2)	40.14	41.49	35.92	35.03	32.76	37.07
Cementation Index	0.618	....	....	....	1.39	

Analyses 1-5 inclusive were made by W. A. Noyes. Quoted by Siebenthal, 25th Ann. Rep. Indiana Dept. Geology and Natural Resources, pp. 380-386.

1. Rock used for "Crown" brand, Hausdale mill, New Albany Cement Company.
2. " " " "Fern Leaf" brand, Ohio Valley mill, Ohio Valley Cement Company.
3. " " " "Diamond" brand, Falls City mill, Union Cement and Lime Co.
4. " " " "Star" brand, Speed mill, Louisville Cement Company.
5. " " " 'Black Diamond", Black Diamond mill, Union Cement and Lime Co.

Kansas.—The natural-cement district of Kansas is located around Fort Scott, where a 4½-foot bed of natural-cement rock outcrops. The rock is a dark-colored, fine-grained, compact limestone of Carboniferous age. It extends for a considerable distance throughout the State, but as yet has been worked for natural cement only in the immediate vicinity of Fort Scott.

Table 90.

ANALYSES OF NATURAL-CEMENT ROCK, FORT SCOTT, KANSAS.

	1.	2.	3.	4.
Silica (SiO_2)	15.21	17.26	21.80	18.09
Alumina (Al_2O_3)	4.56	2.05	3.70	3.44
Iron oxide (Fe_2O_3)	n. d.	5.45	3.10	4.27
Lime (CaO)	36.52	34.45	35.00	35.32
Magnesia (MgO)	5.07	5.28	3.50	4.62
Carbon dioxide (CO_2)	34.27	32.87	33.00	33.38
Cementation Index	.....	.....	1.68	

1. Smith, Mineral Industry, vol. 1, p. 49.
2. Brown, "Cement Directory", 2d ed., p. 276.
3. Richardson, Brickbuilder, vol. 6, p. 151. July, 1897.
4. Average of preceding analyses.

Maryland.—The natural-cement industry of Maryland has been carried on in three separate areas. One of these areas—including the old plants at Antietam and Shepherdstown—will be described later under the heading of West Virginia-Maryland. The other two areas include respectively the plants at Cumberland and Potomac in Allegany County, and that at Round Top or Hancock in Washington County. In both of these areas the limestones used are of the same geologic age, and approximately of the same composition, so that they will here be described together. Analyses are given in Table 90.

In geologic age the natural-cement rock of the Cumberland-Hancock district corresponds closely to that used in the various New York districts, being assigned by geologists to the Salina group of the Silurian. It is a shaly limestone, varying in color from dark bluish gray to dull black. In the Cumberland area it is exposed in four beds of sufficient thickness to be worked, these cement-beds being separated by shales and limestones. The separate beds vary from 6 to 17 feet in thickness.

Minnesota.—Two natural-cement plants are in operation in Minnesota. One of them is located at Mankato, Blue Earth County, and uses a limestone of the Lower Magnesian (Ordovician) series. The analyses (Table 91) of the raw material used at this plant have been published.

TABLE 91.

ANALYSES OF NATURAL-CEMENT ROCKS, CUMBERLAND AND HANCOCK, MARYLAND.

	1.	2.	3.	4.	5.
Silica (SiO_2)	19.81	24.74	27.1	28.72	22.07
Alumina (Al_2O_3)	7.35	16.74		12.28	12.12
Iron oxide (Fe_2O_3)	2.41	6.30	1.5	5.22	3.36
Lime (CaO)	35.76	23.41	36.40	25.54	30.28
Magnesia (MgO)	2.18	4.09	2.52	1.10	2.47
Alkalies (Na_2O,K_2O)	n. d.	6.18	0.3	n. d.	*
Sulphur trioxide (SO_3)	n. d.	2.22	n. d.	1.53	*
Carbon dioxide (CO_2)	31.74	22.90	31.38	24.40	27.60
Water		n. d.	n. d.		
Cementation Index	1.68	3.15	1.62	3.60	2.29

* Data insufficient for averaging.

1. Hancock, Md. C. Richardson, analyst. Brickbuilder, vol. 6, p. 151. July, 1897.
2. Cumberland, Md. E. C. Boynton, analyst. Quoted by Gillmore, "Limes, Cements, and Mortars", p. 125.
3. Hancock, Md. C. Huse, analyst. Quoted by Gillmore, "Limes, Cements, and Mortars", p. 125.
4. Cumberland, Md. C. Richardson, analyst. Brickbuilder, vol. 6, p. 151. July, 1897.
5. Average of preceding four analyses.

TABLE 92.

ANALYSES OF NATURAL-CEMENT ROCK, MANKATO, MINN.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	16.00	12.14	10.10	16.80	8.90	11.80
Alumina (Al_2O_3)	5.85	4.62	2.78	8.76	3.30	3.46
Iron oxide (Fe_2O_3)	2.73	1.84	1.34	tr.	1.02	tr.
Lime (CaO)	22.40	22.66	25.96	22.20	24.85	24.64
Magnesia (MgO)	14.99	16.84	14.91	11.99	18.49	16.61
Alkalies (K_2O,Na_2O)	0.76	3.52	3.50	4.75	1.53	2.59
Sulphur trioxide (SO_3)	n. d.	0.13	0.26	0.22	0.18	0.22
Carbon dioxide (CO_2)	34.11	39.07	41.29	35.90	41.80	40.85
Cementation Index	1.22	0.88	0.69	1.45	0.58	0.77

1. C. F. Sidener, analyst. 11th Ann. Rept. Minn. Geol. Surv., p. 179.
2–6. Clifford Richardson, analyst. Cement Directory, p. 206.

The second plant is said to be located at Austin, Mower Co. If this location be correct, the limestone used is probably of Devonian age.

ANALYSIS OF NATURAL-CEMENT ROCK, AUSTIN, MINN.

Silica (SiO_2)	15.59
Alumina (Al_2O_3)	
Iron oxide (Fe_2O_3)	2.09
Lime (CaO)	27.55
Magnesia (MgO)	13.80
Sulphur trioxide (SO_3)	0.06
Carbon dioxide (CO_2)	36.84

New York.—In the State of New York natural cement is now manufactured in four distinct localities. These are in order of importance: (1) the Rosendale district in Ulster County, (2) the Akron-Buffalo district in Erie County, (3) the Fayetteville-Manlius district, mostly in Onondaga County, and (4) at Howe's Cave in Schoharie County.

The clayey limestones used in these four districts occur in three different but closely related geological formations, all in the Upper Silurian group. The sequence and relation of these formations, from the top downwards, is shown in the following table.

Formation.	Ulster County.	Schoharie County.	Onondaga County.	Erie County.
Manlius limestone (cement rock).			Worked for cement at Manlius, etc.	Absent.
Rondout limestone (cement rock).	Upper cement-bed of the Rosendale district.	Worked for cement at Howe's Cave.		Absent.
Cobleskill limestone (not used for cement).				
Bertie limestone (cement rock).	Lower cement-bed of the Rosendale district.		Present in Onondaga County but rarely used for cement.	Worked for cement at Akron and Buffalo.

For convenience these districts will be described not in the order of their relative importance but in geographic order, from east to west.

The Rosendale district lies entirely in Ulster County, the principal cement-rock quarries being located at East Kingston, Rondout, Rosendale, Binnewater, Lawrenceville, and High Falls. Two distinct beds are worked at most of these points, differing in chemical composition as well as in geological age. Darton states * that at Rosendale the lower bed, or dark cement rock, averages about 21 feet in thickness, and the upper, or light cement rock, about 11 feet, the two cement-beds being here separated by 14 or 15 feet of worthless limestone. The lower bed lies directly on the Clinton quartzite, the even upper surface

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* 13th Ann. Rept. N. Y. State Geologist, vol. 1, 1894, p. 334.

of which affords an admirable floor for the galleries. For about 18 inches at the bottom the dark cement rock is too sandy for use. With this exception and a few small layers of chert it is all available. At Whiteport the upper bed is 12 feet thick and the lower 18 feet, while they are separated by 17 to 20 feet of limestone.

TABLE 93.

ANALYSES OF NATURAL-CEMENT ROCK, ROSENDALE DISTRICT, N. Y.

	1.	2.	3.	4.	5.	6.	7.	8.
Silica (SiO_2)	10.90	15.37	18.11	18.76	21.32	21.41	23.80	18.52
Alumina (Al_2O_3)	3.40	9.13	4.64	8.34	7.39	10.09	4.17	6.34
Iron oxide (Fe_2O_3)	2.28	2.25	3.00	1.85	1.71		4.71	2.63
Lime (CaO)	29.57	25.50	24.30	25.96	23.75	25.80	22.27	25.31
Magnesia (MgO)	14.04	12.35	14.26	11.07	11.07	10.09	12.09	12.13
Alkalies (K_2O,Na_2O)	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Sulphur trioxide (SO_3)	0.61	n. d.	tr.	1.35	1.90	0.66	0.90	0.90
Carbon dioxide (CO_2)	37.90	34.20	34.01	32.00	30.74	30.93	31.00	33.31
Water	n. d.	1.20	n. d.	n. d.	n. d.		n. d.	n. d.
Cementation Index	.....	.....	.....	.....	.....	.....	.....	1.43

1. Lawrenceville. J. O. Hargrove, analyst. Letter to writer, Oct. 4, 1900.
2. Rondout. L. C. Beck, analyst. "Mineralogy of N. Y.", p. 78.
3. Lawrenceville. J. O. Hargrove, analyst. Letter to writer, Oct. 4, 1900.
4. " " " " " " " "
5. " " " " " " " "
6. " Rosendale district. C. Richardson, analyst. Brickbuilder, vol. 6, p. 151. July, 1897.
7. Lawrenceville. J. O. Hargrove, analyst. Letter to writer, Oct. 4, 1900.
8. Average of preceding seven analyses.

Northward and northwestward from the Rosendale-Rondout district no natural-cement plants are to be found until Schoharie County is reached. Here, at Howe's Cave, a single plant has long been engaged in the manufacture of cement from a 7-foot bed of rock.

TABLE 94.

ANALYSES OF NATURAL-CEMENT ROCK, SCHOHARIE COUNTY, N. Y.

	1.	2.	3.
Silica (SiO_2)	12.89	9.92	11.50
Alumina (Al_2O_3)	11.15	n. d.	
Iron oxide (Fe_2O_3)		n. d.	1.50
Lime (CaO)	30.90	38.26	31.75
Magnesia (MgO)	9.38	9.00	14.91
Carbon dioxide (CO_2)	34.60	39.96	40.34
Cementation Index	1.07		

1. Bottom of cement-bed, Howe's Cave. C. O. Schaeffer, analyst. 18th Ann. Rept. N. Y. State Geologist, p. 69.
2. Top of cement-bed, Howe's Cave. C. O. Schaeffer, analyst. 18th Ann. Rept. N. Y. State Geologist, p. 69.
3. Howe's Cave. L. C. Beck, analyst. "Mineralogy of New York", p. 79.

The cement industry in central New York is at present practically confined to Onondaga County, though as a matter of historical interest it may be noted that the first natural cement made in the United States was manufactured in 1818 in Madison County.

The natural-cement rock of this central district occurs in two beds which are usually separated by 1 to 4 feet of blue limestone. The upper cement-bed is a little over 4 feet thick at the eastern border of Onondaga County, becoming thinner to the westward until it pinches out entirely in the the Split Rock quarries, but reappearing again at Marcellus Falls, where it is almost 3 feet thick and showing a thickness of slightly over 4 feet at Skaneateles Falls. At this last point it is separated from the lower cement-bed only by a shaly parting a few inches thick, so that the two are worked together as practically one bed 9½ feet thick. The lower bed is less variable in thickness, ranging from 4 to a trifle over 5 feet.

The entire cement series is overlaid by purer limestones, but the cement-rock quarries are usually located at points where these overlying limestones are thin and can be readily stripped.

TABLE 95.

ANALYSES OF NATURAL-CEMENT ROCK, CENTRAL NEW YORK.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	10.97	10.95	13.50	8.95	11.76	10.66
Alumina (Al_2O_3)	4.46	5.32		4.90	2.73	4.35
Iron oxide (Fe_2O_3)	1.54	1.30	1.25	1.75	1.50	1.47
Lime (CaO)	27.51	30.92	25.24	27.35	25.00	27.20
Magnesia (MgO)	16.90	13.64	18.80	16.70	17.83	16.77
Carbon dioxide (CO_2)	37.94	38.31	39.80	38.65	39.33	38.81
Water	n. d.	n. d.	1.41	1.70	1.50	1.53
Cementation Index	.....	.....	.....	.....	.....	0.71

1. Upper cement-bed, E. B. Alvord quarry, Jamesville, Onondaga County. Bull. 44 N. Y. State Mus., p. 806.
2. Lower cement-bed, E. B. Alvord quarry, Jamesville, Onondaga County. Bull. 44 N. Y. State Mus., p. 806.
3. One and one half miles west of Manlius, Onondaga County. L. C. Beck, analyst. "Mineralogy of New York", p. 81.
4. One and one half miles southwest of Chittenango, Madison County. L. C. Beck, analyst. "Mineralogy of New York", p. 80.
5. Chittenango, Madison County. Seybert, analyst. Trans. Am. Philos. Soc., vol. 2, n. s., p. 229.
6. Average of preceding five analyses.

In Erie County natural-cement plants have long been established at Akron and Buffalo. The bed of cement rock used varies in thickness from 5 to 8 feet. "It is a firm, fine-grained compact rock of a blue-gray color, weathering to a yellowish white. The Buffalo plant works its cement rock by quarrying methods, stripping off the overlying limestones; but the plants at Akron all obtain their raw material by mining.

TABLE 96.

ANALYSES OF NATURAL-CEMENT ROCKS, AKRON-BUFFALO DISTRICT, NEW YORK.

	1.	2.	3.	4.
Silica (SiO_2)	9.03	10.68	33.80*	9.85
Alumina (Al_2O_3)	2.25	4.61	3.96	3.10
Iron oxide (Fe_2O_3)	0.85		0.88	0.87
Lime (CaO)	26.84	25.65	19.93	26.25
Magnesia (MgO)	18.37	17.93	9.17	18.15
Alkalies (K_2O,Na_2O)	0.85	n. d.	n. d.	
Sulphur trioxide (SO_3)	n. d.	n. d.	0.50	
Carbon dioxide (CO_2)	40.33	.....	25.90	
Water	0.98	.....		
Cementation Index	.....	.....	.....	0.610

* Called "silica, clay, and insoluble silicates".

1. G. Steiger, analyst. Bulletin 168, U. S. Geol. Survey.
2. Lathbury and Spackman, analysts.
3. E. Boynton, analyst. Gillmore, "Limes, Cements, and Mortars", p. 125.
4. Average of analyses 1 and 2.

I am informed by Mr. Uriah Cummings, of the Cummings Cement Co., Akron, N. Y., that none of the analyses given in Table 96 are really representative of the Akron natural-cement rock. The analyses are presented, therefore, subject to this criticism.

North Dakota.—The single natural-cement plant operating in this state is located about ten miles east of Milton, Cavalier County. The rock used is a soft, chalky limestone of Cretaceous age and outcrops in a bluff several hundred feet high. At present, however, only a 10-foot bed is being worked, by mining. (See Table 97.)

Ohio.—Small natural-cement plants have been established at various points in Ohio, those at Defiance and New Lisbon being worthy of some notice. The Defiance plant used a black calcareous shale of Devonian age. If published analyses be correct (see Nos. 1 and 2 in Table 98) this rock is by far the most argillaceous material used anywhere for this purpose.

Pennsylvania.—A fairly large production of natural cement has always been maintained in the Lehigh district of eastern Pennsylvania, though at present natural-cement manufacture there is merely incidental to the great Portland-cement industry of the district.

The analyses given in Table 99 purport to be representative of the rock used at various Lehigh district natural-cement plants. It is hardly

TABLE 97.

ANALYSES OF NATURAL-CEMENT ROCK, NORTH DAKOTA.

	1.	2.	3.	4.	5.
Silica (SiO_2)	14.00	16.60	13.10	16.20	16.54
Alumina (Al_2O_3)	6.70	7.10	7.60	7.56	8.20
Iron oxide (Fe_2O_3)					
Lime (CaO)	37.60	35.50	37.80	35.10	35.20
Sulphur trioxide (SO_3)	0.58	0.60	n. d.	n. d.	n. d.
Sulphur (S)	1.45	1.38	n. d.	n. d.	n. d.
Cementation Index	1.24				

	6.	7.	8.	9.	10.
Silica (SiO_2)	14.90	15.24	19.20	17.36	16.00
Alumina (Al_2O_3)	8.28	7.26	8.90	8.78	7.50
Iron oxide (Fe_2O_3)					
Lime (CaO)	36.90	36.70	32.60	34.90	35.60
Sulphur trioxide (SO_3)	n. d.	0.40	n. d.	n. d.	0.67
Sulphur (S)	n. d.	1.99	n. d.	n. d.	1.61
Cementation Index	.....	.....	1.92		

TABLE 98.

ANALYSES OF NATURAL-CEMENT ROCKS, OHIO.

	1.	2.	3.	4.	5.
Silica (SiO_2)	39.95	42.0	16.41	30.60	15.65
Alumina (Al_2O_3)	20.22	7.0	5.44	13.00	6.8
Iron oxide (Fe_2O_3)		7.1	3.38		2.5
Lime (CaO)	10.06	9.91	26.05	22.74	38.64
Magnesia (MgO)	2.92	5.81	12.55	7.23	1.62
Carbon dioxide (CO_2)	24.03	14.18	34.32	25.81	32.14
Water and organic		14.0	n. d.	n. d.	n. d.
Cementation Index	.....	.....	.....	.....	1.25

1. Defiance. J. E. Whitfield, analyst. Bull. U. S. Geol. Survey No. 55, p. 80.
2. Defiance. R. C. Kedzie, analyst. Cement Directory.
3. Bellaire. N. W. Lord, analyst. Repts. Ohio Geol. Surv., vol. 6, p. 673.
4. Warnock. Wormley, analyst. Rept. Ohio Geol. Surv., 1870, p. 451.
5. New Lisbon. N. W. Lord, analyst. Rept. Ohio Geol. Surv., vol. 6, p. 673.

necessary to say that Nos. 1 and 3 are absolutely unfit for such use. No. 2, on the other hand, is quite satisfactory. I regret that these very untrustworthy analyses are, at present, the only ones available.

Texas.—The second analysis on p. 212 has been published * as representing the average of the material used in making natural cement by a

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* 22d Ann. Rept. U. S. Geol. Survey, pt. 3, p. 737.

TABLE 99.

ANALYSES OF NATURAL-CEMENT ROCK, LEHIGH DISTRICT, PA.

	1.	2.	3.	4.
Silica (SiO_2)	11.62	18.34	27.77	19.24
Alumina (Al_2O_3)	6.25	7.49	14.29	9.34
Iron oxide (Fe_2O_3)				
Lime (CaO)	44.20	37.60	29.94	37.25
Magnesia (MgO)	1.27	1.38	1.55	1.40
Carbon dioxide (CO_2)	36.11	31.06	26.30	32.47
Water	n. d.	3.94		
Cementation Index	0.843	1.49	2.87	

1. Siegfried, Pa. Mineral Industry, vol. 1, p. 49.
2. Coplay, Pa. Mineral Industry, vol. 1, p. 49.
3. Lehigh district. Quoted by C. Richardson. Brickbuilder, vol. 6, p. 151. July, 1897.
4. Average of preceding three analyses.

Texas natural-cement plant. It is obvious that, if this statement be correct, the product obtained by burning a rock of such composition cannot be a natural cement in any proper use of the term. It would, in fact, be merely a very weak hydraulic lime.

ANALYSIS OF NATURAL-CEMENT ROCK, TEXAS.

Silica (SiO_2)	5.77
Alumina (Al_2O_3)	2.14
Iron oxide (Fe_2O_2)	
Lime (CaO)	50.45
Magnesia (MgO)	0.28

Virginia.—For many years natural cement has been burned near Balcony Falls, Rockbridge County, Va. The rock used is a clayey magnesian limestone of Cambrian age, closely related geologically and technologically to that described below as being used in West Virginia.

TABLE 100.

ANALYSES OF NATURAL-CEMENT ROCK, VIRGINIA.

	1.	2.	3.
Silica (SiO_2)	17.38	17.21	17.30
Alumina (Al_2O_3)	7.80	tr.	6.18
Iron oxide (Fe_2O_3)		1.62	1.62
Lime (CaO)	34.23	24.85	29.54
Magnesia (MgO)	9.51	16.58	13.05
Carbon dioxide (CO_2)	30.40	37.95	34.17
Cementation Index	.....	.....	1.18

1. Balcony Falls. E. C. Boynton, analyst. Gillmore, "Limes, Cements, and Mortars", p. 125
2. Balcony Falls. C. L. Allen, analyst. "The Virginias", vol. 3, p. 88.
3. Average of preceding two analyses.

West Virginia–Maryland.—A wide belt of magnesian limestones of Cambrian age crosses Maryland into the eastern part of West Virginia. Several small natural-cement plants have been established in this district at various times, particularly near Antietam, Md., and Shepherdstown, W. Va.

ANALYSIS OF NATURAL-CEMENT ROCK, ANTIETAM, MD.

	(1)
Silica (SiO_2)	15.97
Alumina (Al_2O_3)	7.59
Iron oxide (Fe_2O_3)	
Lime (CaO)	23.72
Magnesia (MgO)	15.6
Alkalies (K_2O,Na_2O)	n. d.
Sulphur trioxide (SO_3)	0.71
Carbon dioxide (CO_2)	34.82
Water	
Cementation Index	1.14

(1). Antietam, Md. C. Richardson, analyst. Brickbuilder, vol. 6, p. 151.

Wisconsin.—Two plants in Wisconsin are engaged in the manufacture of natural cement from a clayey magnesian limestone of Devonian age. These plants are located north of Milwaukee, near the lake. The cement-rock deposit is very thick, compared to most natural-cement propositions, a quarry face 22 feet high being worked by the Milwaukee Cement Company.

TABLE 101.

ANALYSES OF NATURAL-CEMENT ROCKS, MILWAUKEE DISTRICT, WIS.

	1.	2.	3.	4.	5.
Silica (SiO_2)	17.00	17.56	17.56	16.99	17.28
Alumina (Al_2O_3)	4.25	1.41	1.40	5.00	3.02
Iron oxide (Fe_2O_3)	1.25	3.03	2.24	1.79	2.21
Lime (CaO)	24.64	25.50	27.14	23.15	25.11
Magnesia (MgO)	11.90	15.45	13.89	16.60	14.46
Carbon dioxide (CO_2)	32.46	37.05	36.45	36.47	n. d.
Cementation Index	.....	.....	.....	.....	1.18

1. Mineral Industry, vol. 6, p. 95.
2. Trans. Am. Inst. Min. Engrs., vol. 8, p. 507.
3. " " " " " " " " "
4. " " " " " " " " "
5. Average of preceding four analyses.

European Natural-cement Rocks.

As noted later, the European natural-cement industry dates back to 1796, in which year the manufacture of natural cement was commenced simultaneously in France and England. At present the industry is established in practically every country of Europe, though it is of course subject to severe competition from Portland cement on the one hand and the better class of hydraulic limes on the other. European natural cements form two fairly distinct classes, which are there called respectively "natural Portlands" and "Roman cements":

(1) The **natural Portlands,** which are described on pages 215–217 in detail, are natural cements of low cementation index (1.05 to 1.15 usually), low in magnesia, and burned at fairly high temperatures. In consequence of the combination of their low index and relatively high burning, these products approach true Portland cements in analysis and physical properties, though they necessarily vary considerably from time to time according to the rock from which they are made. The best of these products will pass low-grade Portland tests, and were formerly largely exported to this country, where they were unloaded on the architects and engineers who specified "foreign Portland cement". The poorer "natural Portlands" are often adulterated with slag or unburned limestone, in order to make their bulk composition agree on analysis with that of true Portlands.

While the "natural Portlands" are often useful products, there seems to be no reason for classing them with the true Portlands, for the term Portland is now understood to imply that a very careful and finely ground artificial mixture has been made before burning.

(2) The **Roman cements** form the second class of European natural cements. They are usually cements of moderately high index (1.20 to 1.60), and are also usually but not invariably low in magnesia. They correspond therefore quite closely, so far as index is concerned, to the best of the American natural cements. In American practice, however, low-magnesia natural cements are quite rare, as can be seen by referring to the tables of analyses on pages 253 to 260, while in Europe high-magnesia cements are very scarce.

It may be of interest to call attention here to the fact that quick-setting *artificial* cements of high index (1.20 to 1.60), and very lightly burned, have been made at several points in Europe. These products would correspond in every way with our natural cements, except in that they are made from artificial mixtures and are therefore more expensive to make. Wherever a good natural-cement rock is obtainable, therefore, these "artificial-natural" cements are driven out of the market.

Natural-cement materials of Belgium.—"Natural Portland" cement, as well as Roman cement, is extensively manufactured in certain parts of Belgium.

The following analysis is representative of the composition of the rock from which these "natural Portlands" are made:

Silica (SiO_2)	15.75
Alumina (Al_2O_3)	3.95
Iron oxide (Fe_2O_3)	1.00
Lime (CaO)	43.10
Magnesia (MgO)	0.49
Sulphur trioxide (SO_3)	0.50
Carbon dioxide (CO_2) Water	35.21
Cementation Index	1.12

It will be seen that if rock of the composition represented by the above analysis could be steadily obtained it would certainly be an excellent natural mixture for a Portland cement. In composition it is admirable, while its index is about that of the average commercial Portland. In practice, however, the variations in composition of the rocks from various parts of the quarry are sufficient to prevent the product from being sufficiently uniform to be considered a Portland cement in our modern use of that term. This will be seen on referring to the analyses of these Belgian products given on page 261.

A report* on the Belgian cement industry states:

"The most important center for the manufacture of natural and artificial Portland cement in Belgium is the calcareous district of Tournai, in the consular district of Brussels. Some of the quarries in this district date back several centuries, when they were principally worked for building stone and for the manufacture of hydraulic lime. The calcareous stone of these quarries, which originated the now extensive and important industry of cement-manufacture, extends for many miles in length in apparently inexhaustible quantity. Ordinary lime, best hydraulic lime, slow-setting cement (Portland), and quick-setting cement (Roman) are especial products of these immense quarries.

"Natural Portland cement is obtained from calcareous stone, which is carefully analyzed and dosed, calcined in coke-heated kilns, and, after burning, finely pulverized. Before burning, the stone presents a fine,

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* Roosevelt, R. W. Manufacture of Portland cement in Belgium,

close grain and is of a peculiar pasty appearance. Prior to calcination the stone is carefully analyzed, to ascertain the exact quantity of lime, as well as other chemical properties, it may contain. The stone loses about one third of its weight during the process of burning, which also changes it to a brown tinge. When withdrawn from the kiln the cement is put under sheds to thoroughly cool before being ground. After grinding and before being barreled it is put into pits and left undisturbed for two months.

"Natural Portland cement was first manufactured in Belgium in 1882. The following are the principal works now engaged in this enterprise: Compagnie Générale des Ciments Portland de l'Escaut, Dumon et Cie, and Goblet, Delward et Cie, Tournai; Société Anonyme de Chercg, Chercg; L'Union Fraternelle, La Franco-Belge, and Dutoit & Tell frères, Calonne; Lemain & Fleury, Lampe et Cie, and Société Anonyme du Cancan, Antoing; V^{ve} Alex. Dapsens and Duquesne et Cie, Vaulx; Laurent Delvigne & fils, Gaurany; the United Ghent-Antwerp Portland Cement Works, Ghent. With few exceptions, these establishments have formed a syndicate, under the name of 'Mutualite Commerciale des Ciments Belges', with headquarters at Tournai. The society sells about 1,200,000 barrels of cement annually. The syndicate has adopted as a trade-mark the figure of a hammer. Any firm, however, of the syndicate having a trade-mark is privileged to use it. For instance, those firms having the well-known 'rhinoceros', 'trowel', 'sword', etc., use them in conjunction with the syndicate trade-mark. Independently of the trade-marks of the manufacturers, important buyers of the Mutualite who have labels enjoying a certain reputation are permitted to affix them on the barrels. It is stated that the principal object of this arrangement by the Belgian manufacturers is to warn and protect purchasers against persons who purchase Roman cement for export without mark or label and unknown and unauthorized by the manufacturers have Portland-cement labels affixed to the barrels at port of shipment. The Mutualite has sent circulars to interested parties in the United States informing them of the measures adopted to prevent this fraud. Hereafter all barrels containing cement manufactured, shipped, or sold by this syndicate will be fire-marked as follows: First quality, inside and outside of barrel, 'Portland Warranted M. C. B.'; second quality, inside only, 'Deuxième quality'; third quality, inside only, 'Ciment Romain'.

"Roman cement is also manufactured in the Tournai district. It is much cheaper than Portland cement, the selling price being about 50 per cent less than the Portland. It is much employed in Belgium, replacing, advantageously, a good hydraulic lime. Manufacturers, however, will not guarantee it, as it is made of refuse stone not suitable for the manufacture of Portland cement. It has a natural light-yellow color. Cinders are very often added, changing it to a grayish color resembling Portland cement, and also increasing its resistance in a slight degree. This is the product which is purchased by unscrupulous exporters and sold by them marked as Portland cement. This fact is significant and should attract the attention of builders, to avoid disasters such as the unexpected collapse of buildings, where first-class cement has been supposed to have been employed ".

Fig. 34 shows the results of a series of tests of American Portlands, American natural cements, and Belgian "natural Portlands". These results may be accepted as quite representative of the various types of cements tested, and show clearly that the so-called "natural Portlands" have little in common with true or artificial Portlands.

Natural-cement materials of England.—The materials used by Parker, the first manufacturer of English natural cements, were septaria —i.e., nodules of clayey lime carbonate. These occur in certain formations in the south of England, and are still used in the English natural-cement industry. The supply is obtained along the coasts, where the nodules have been washed out of the beds which contain them.

TABLE 102

ANALYSES OF NATURAL-CEMENT ROCKS, ENGLAND.

	1.	2.	3.	4.	5.
Silica (SiO_2)	32.00	18.0	17.20	33.00	21.90
Alumina (Al_2O_3)		6.6	6.8		3.50
Iron oxide (Fe_2O_3)		3.7	12.8		8.20
Lime (CaO)	35.28	39.64	29.34	33.88	32.37
Magnesia (MgO)	2.00	0.10	3.33	2.71	2.71
Alkalies (K_2O,Na_2O)	0.80	n. d.	1.00	0.80	1.10
Carbon dioxide	29.92	29.46	26.73	29.61	28.42
Water	n. d.	1.30	2.80	n. d.	1.80

1. Sheppey septaria. Redgrave, "Calcareous Cements", p. 49.
2. Sheppey septaria. Berthier, analyst. Burnell, "Limes, Cements, Mortars, etc.", p. 80.
3. Sheppey septaria. Knauss, analyst. Zwick, "Hydraulischer Kalk und Portland-Cemente", p. 69.
4. Harwich septaria. Redgrave, "Calcareous Cements", p. 49.
5. Harwich septaria. Knauss, analyst. Zwick, "Hydraulischer Kalk und Portland-Cemente", p. 69

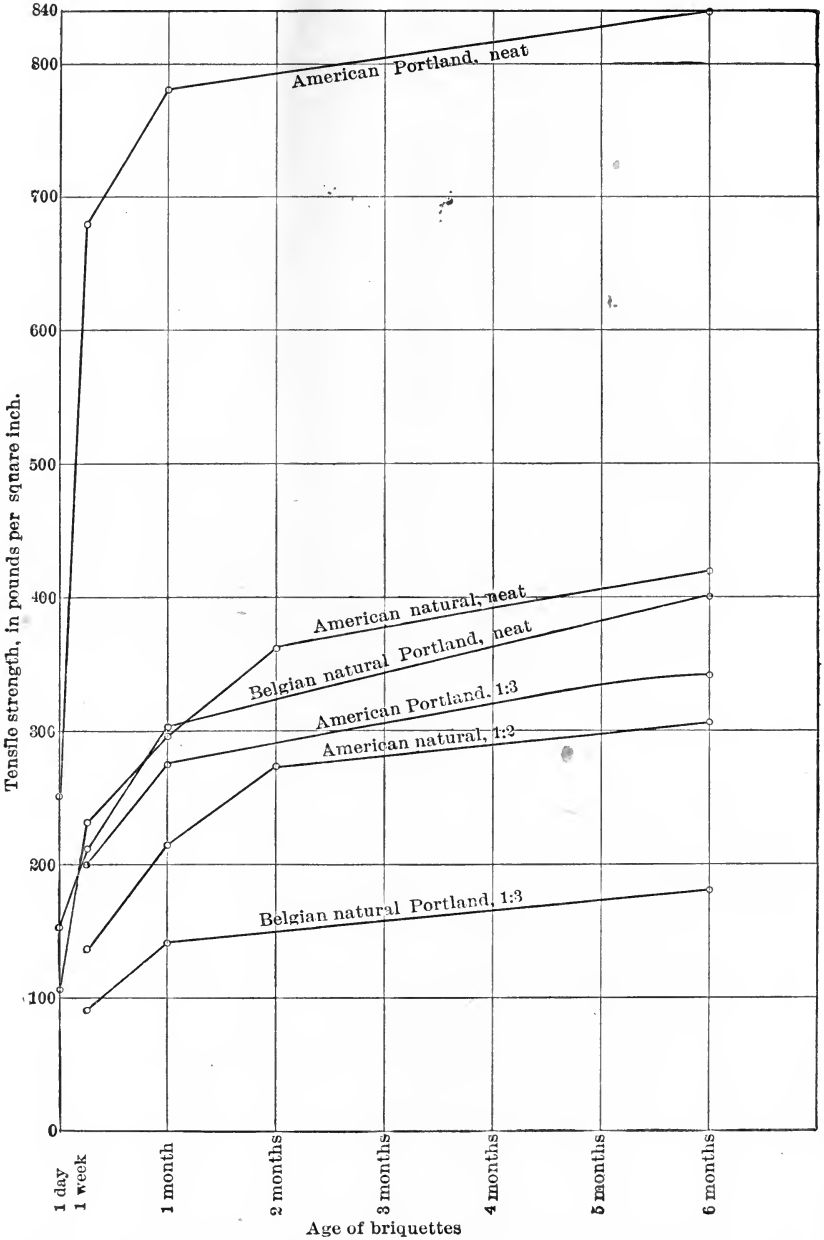

FIG. 34.—Tensile strength of various classes of cement. (Philadelphia tests, 1897.)

Excavation of the Rock.*

In excavating a natural-cement rock the preferable method of working, so far as cheapness is concerned, is quarrying. But so many of the natural-cement beds now worked are thin (from 4 to 8 feet in total thickness) or occur in such steeply inclined positions, that a surprisingly large percentage of the raw material is obtained by mining. In the Rosendale district of New York, for example, mining is the common mode of extracting the rock; and the same is true of the plants in the Akron district, New York, of those in Maryland, North Dakota, Illinois and Kansas, of the Howard plant in Georgia, and of many of the Louisville district plants. The plants of the Milwaukee district, the Rossville

Fig. 35.—Loading cars, Speed quarry, Speeds, Ind.

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* Further details concerning quarrying costs and methods will be found on pages 367–381.

plant in Georgia, a number of those in the Louisville district, and several others work open quarries.

This difference in general practice, taken in connection with differences in labor costs, etc., causes a wide variation between different plants in the total cost of raw material delivered at the kilns.

Open quarries can be readily worked at costs of from 20 to 35 cents per ton of rock. In most cases the question of handling stripping economically is more important than the costs of actual quarrying. At one of the Louisville district plants, where hoists are used in the quarry (Fig. 35) for loading the cars, the stripping is removed by scrapers whose power is derived from these hoists.

In an area such as the Rosendale district, where practically all the cement rock is won by mining, costs will naturally be higher than where open quarries are operated. At one of the largest mills the rock can be delivered on top of the kilns for a trifle under 50 cents per ton. I am informed that at another large mill, rock was mined for a series of years at a cost of about 35 cents per ton.

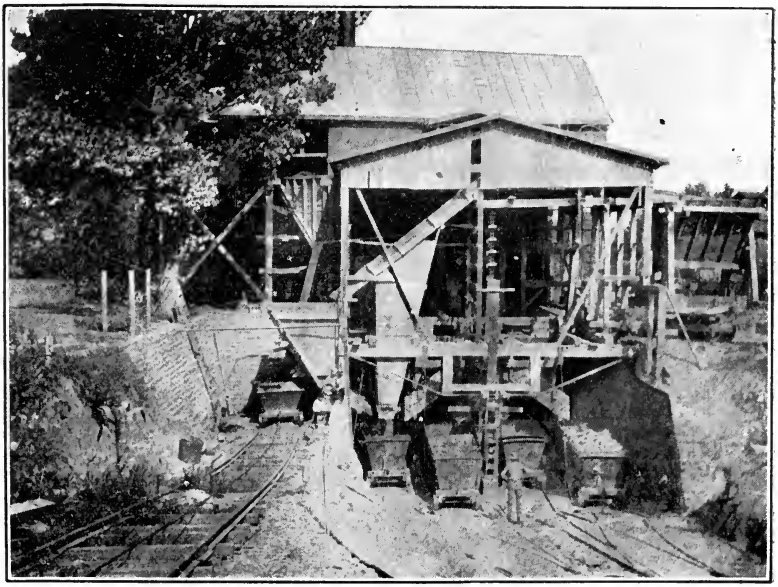

FIG. 36.—Crusher for raw rock at Speed mill, Speeds, Ind.

Summing up these considerations, it is probably within safe limits to say that the cost per ton of rock may vary from about 20 cents in a well-managed quarry to perhaps 60 cents or even more in a mine.

As the rock will lose from 25 to 40 per cent of weight during the process of burning (averaging about 33⅓ per cent), the cost per ton of burned rock will vary from 30 to 90 cents. Reducing this to terms of barrels of cement, the cost of raw material per barrel of finished cement may range from 4 to 13 cents.

After the raw material has been excavated, no preliminary treatment is strictly necessary before sending it to the kilns. It is advisable, however, to feed the kilns with lumps of approximately equal size, because if the charge consists of a mixture of large and small masses of rock the latter will be overburned before the former are properly calcined. In most plants this rough sizing is accomplished by sledging the larger pieces at the quarry. A few plants, however, use crushers, one installation being illustrated in Fig. 36.

References on natural-cement rock.—The natural-cement rocks of the various states are described more fully in the reports and papers listed below. For convenience these have been arranged by States in alphabetical order.

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CHAPTER XVIII.

MANUFACTURE OF NATURAL CEMENTS.

The manufacture of natural cement is, compared to that of Portland cement, a very simple proposition from a mechanical point of view. Only two general processes are involved—burning and grinding. In the present chapter these processes will be taken up separately, after which a brief statement will be given as to costs of manufacture.

Burning Practice and Theory.

Before taking up such practical questions as types of kiln used, kinds of fuel, relation of fuel consumption to output, etc., it seems advisable to discuss briefly certain more theoretical aspects of the process of burning. On examination, however, it will be found that even these apparently theoretical phases of the subject have a distinct practical bearing.

Chemical changes during burning.—The rock as it is charged into the kiln is a clayey limestone, consisting essentially of lime carbonate and more or less magnesium carbonate, with clayey matter (silica, alumina, and iron oxide). In addition to these essential ingredients it will usually contain a few per cent each of alkalies (soda and potash), sulphur or sulphur trioxide, and water. During calcination certain chemical changes take place in about the following order.

Any mechanically held water is driven off before the rock has reached a temperature of much over 100° C. (212° F.). At about 400° C magnesium carbonate begins to be dissociated, its carbon dioxide being driven off and the magnesia remaining in its caustic and active form. When mixed with lime carbonate, as in natural-cement rock, it is probable that this dissociation does not take place much below 700° C. When the rock reaches 750° to 800° C. its lime carbonate is dissociated in like manner. At a somewhat higher temperature its clay is decomposed and combination between the alumina and iron oxide and the lime and magnesia commences. This is aided by the presence of alkalies, which here act as fluxes.

It is probable that some natural cements are burned at temperatures not exceeding 900° C., in which case their strength depends largely on the formation of aluminates and ferrites. When, as in most cases, the temperature is carried to 1100°–1300° C., the silica is attacked and lime and magnesia silicates are formed.

Relation of composition to degree of burning.—It may be set down as a general principle that:

The lower the Cementation Index the higher the temperature that must be reached to secure thorough combination.

A cement with an index of 2.00, for example, can be burned at a temperature little, if any, above that of an ordinary lime-kiln (900° C.), while a cement whose index falls below 1.10 will require a temperature almost equal to that (2300° F.) attained in a Portland-cement kiln.

There are therefore distinct economic advantages, so far as fuel consumption is concerned, in making a cement with a high Cementation Index. It must, however, be recollected that *if the burning is properly done, a cement of low index will be stronger than one of high index.*

By far the most satisfactory proposition to handle, from the manufacturer's point of view, is a product whose index falls between 1.20 and 1.60. Such a rock, if properly burned, will give a cement strong enough to compare favorably with the best American or foreign naturals, while, on the other hand, there is no particular danger of making an unsound product. With an index between these limits the burning temperature may vary considerably, one way or the other, without any danger of leaving too much free lime or magnesia in the clinker. With a cement whose index falls below 1.10 this is not true, for the margin of safety is so narrow that the temperature must be kept up to its highest point under penalty of producing unsound cement.

Losses in burning, etc.—If all the rock fed to the kiln were perfectly burned, the loss in burning would correspond directly to the percentage of carbon dioxide (CO_2) plus water present in the raw rock. On this basis one ton (2000 lbs.) of rock would produce the number of barrels (280 lbs.) of cement given in Table 102.

In actual practice, however, a very large additional percentage must be deducted for losses by overburning or underburning. Bad weather and bad management may carry this loss from clinkering or underburning to a point where one third of the product of the kiln is spoiled. Improved kilns may reduce the loss from these causes to about 10 per cent, and anything between these limits (10 per cent and 33$\frac{1}{3}$ per cent) may be expected at a natural-cement plant. Under average conditions I should say that 25 per cent would be a safe allowance.

CO_2+ water.	Clinker.	Cement.
Per Cent.	Pounds.	Barrels.
25	1500	5.36
26	1480	5.28
27	1460	5.21
28	1440	5.14
29	1420	5.07
30	1400	5.00
31	1380	4.93
32	1360	4.85
33	1340	4.78
34	1320	4.71
35	1300	4.64
36	1280	4.57
37	1260	4.50
38	1240	4.43
39	1220	4.36
40	1200	4.28

Types of kiln used.—With but few exceptions the kilns used in the American natural-cement industry are of the vertical continuous mixed-feed type.* That is to say, the rock and fuel are fed to the kiln either mixed together or in alternate layers. Kilns of the separate-feed type, in which the fuel does not come in contact with the rock but is burned in a separate furnace, are rarely used in the cement industry. In the lime industry separate-feed kilns are rapidly supplanting the mixed-feed kilns, but the reasons for using them in burning lime do not hold in burning cement. The principal advantage of the separate-feed kiln is that it gives a clean white product unmixed with fuel ashes. This is, of course, a distinct advantage to a lime manufacturer, but it would be of little importance in the cement industry. On the other hand, the mixed-feed kilns are apparently more economical of fuel than the others.

The attention of American natural-cement manufacturers might be profitably turned to consideration of some of the improved types of continuous kilns. The Aalborg kiln, for example, described on pages 101–103, is used in hydraulic-lime manufacture in Europe, and gives remarkably good results as to fuel consumption and quality of product.

The Campbell kiln is not, properly speaking, a new type of kiln, but rather a kiln containing a new type of "pot". In the ordinary lime

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* On pp. 99 to 108 will be found descriptions of the various types of kilns used in the lime industry. These descriptions may be referred to as being of interest in the present connection.

or natural-cement kiln the pot or lower portion of the kiln is an inverted oval in shape, with one or more draw-chutes or doors at the side. This results in a certain amount of concentration of the heat, as the draft is localized near the base of the kiln owing to the effects of the draw-openings. The Campbell kiln-pot, instead of being an inverted egg-shaped mass of solid masonry, is an open grating in the form of an inverted cone. In Figs. 38 and 39 the construction details of the kiln are clearly shown. It will be seen in the front elevation that an open space is left all around the pot, between the grating and the supporting walls of the kiln, so that the drawer has free access to all parts of the grating in case of choking or other difficulty. The openings in the grating distribute the air-supply so that the draft is uniform throughout the kiln.

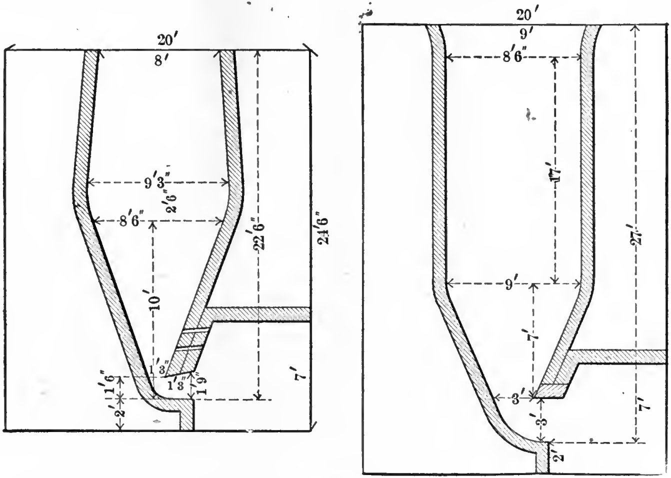

FIG. 37.—Sections of kilns used in natural-cement plants. (After Gillmore.)

It is stated * that the cost of reconstructing the iron-cased kilns of the Milwaukee Cement Company on the Campbell pattern was about $250 per kiln. For a stone kiln the cost of reconstruction would be somewhat higher. A new Campbell kiln, however, would cost somewhat less than a new kiln of ordinary pattern, for the iron "pot" will displace more than its equivalent value of brick and labor.

The Campbell kilns in use at the plant of the Milwaukee Cement Company hold a charge equivalent to about 400 barrels (265 lbs. each) of cement. This is drawn at the rate of 125 to 130 barrels per day,

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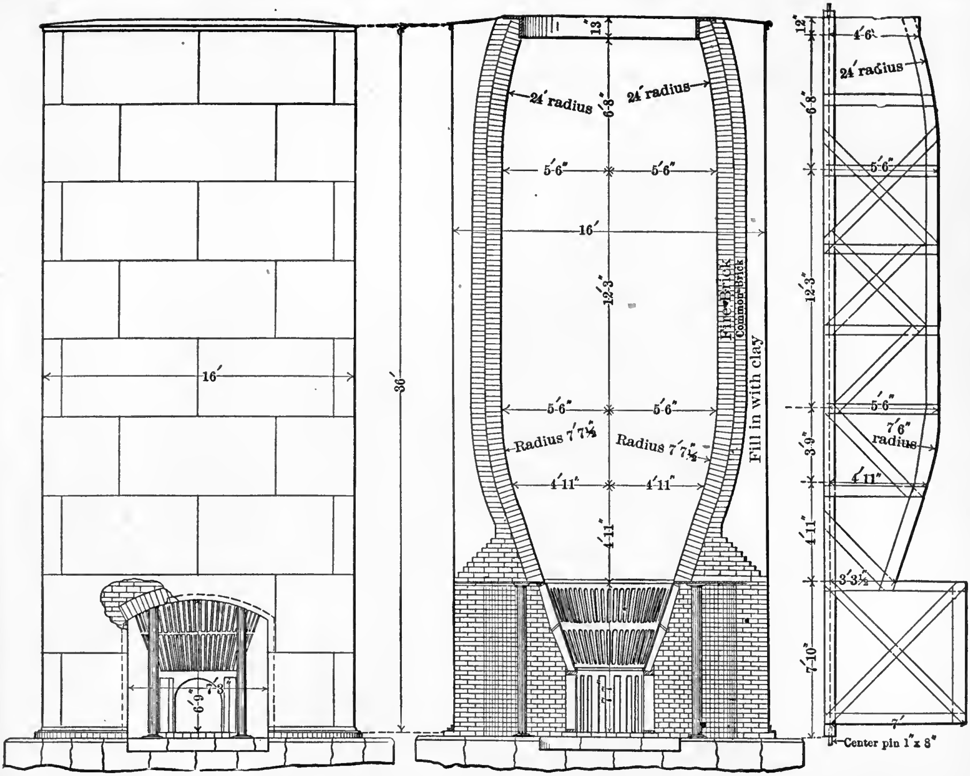
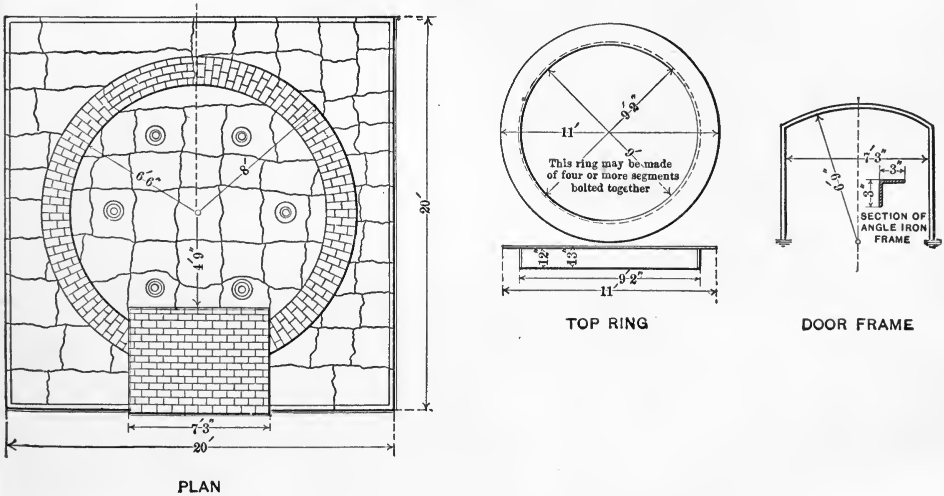
* Engineering News, Dec. 23, 1897.



FRONT ELEVATION SECTION TEMPLATE

Fig. 38.—Elevation and section of the Campbell kiln.



PLAN TOP RING DOOR FRAME

Fig. 39.—Plan and details of the Campbell kiln.

all the drawing for the day being done in ten hours. Nut and slack coal, mixed, are used for fuel. The fuel consumption amounts to about 30 lbs. per barrel of cement, equivalent to 11.3 per cent on the weight of the cement produced.

At the Pembina plant in North Dakota a kiln 40 feet high and 10 feet in external diameter is used. The shell is of $\frac{1}{8}$-inch No. 14 boiler iron. The klin space is broadest at the top, narrows about 6 feet down to a throat about 6 feet in diameter, below which it again enlarges, reaching almost to the kiln-shell at 15 feet above the base. Below this it is again somewhat contracted to the drawing level. The kiln space is lined with 8-inch fire-brick and the space between these brick and the kiln-shell is filled with ashes. This kiln produces about 50 barrels of 265 lbs. each per day, with a fuel consumption of one ton of Youghiogheny slack. Lignite slack, mixed half and half with Youghiogheny slack, has been used

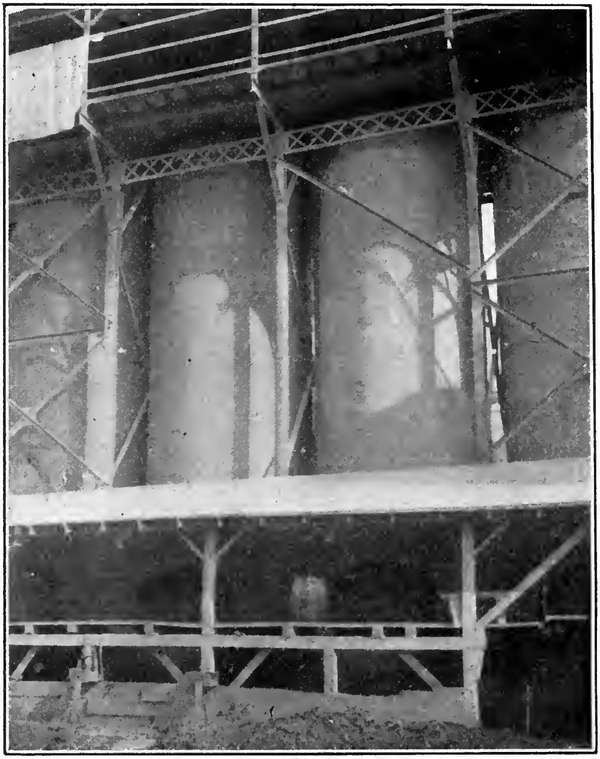


Fig. 40.—Kilns of the Lawrence plant, Siegfried, Pa.

at times, and apparently gives almost as good results as the bituminous slack alone. About 10 per cent of the total product is underburnt, or clinkered. This record is about equivalent to a fuel consumption of 40 lbs. per barrel, or 15.1 per cent, on the weight of cement produced. This is rather high fuel consumption for natural cement, but, on the other hand, the product is of peculiarly high grade, passing most Portland standards.

The natural-cement kilns at one of the prominent Lehigh district plants are about 30 feet in height and of circular cross-section. Internally they are almost exactly cylindrical, being 10 feet in diameter at the top and 9½ feet in diameter at the base. The cement rock and fuel are fed in alternate layers, the fuel being anthracite coal broken to about ½-inch size. From 35 to 50 lbs. of coal are required to burn one barrel (300 lbs.) of cement, corresponding to a fuel consumption of 11.6 to 16.7 per cent of the weight of cement produced.

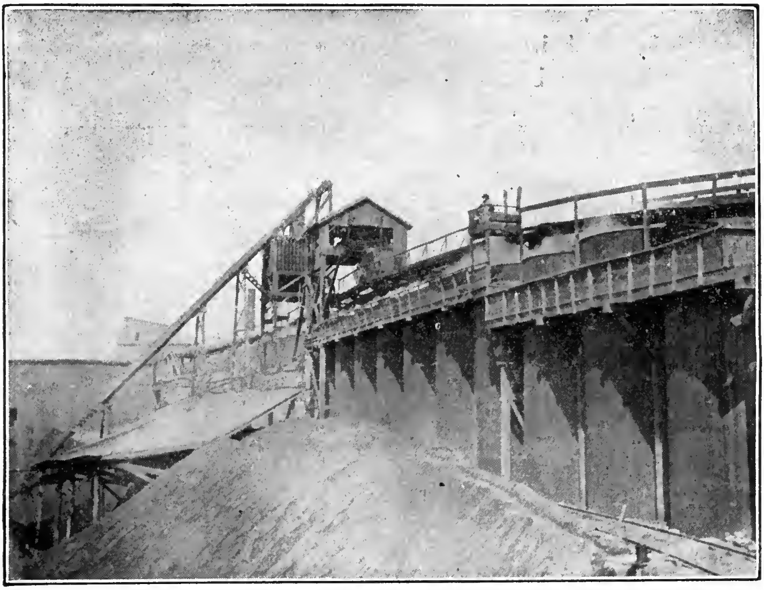


Fig. 41.—Kilns and coal-conveyor of the Speed plant, Speeds, Ind.

Two styles of kiln are in use in the Louisville district. The older and smaller kilns are 36 feet in height, 8 feet in diameter at the top, enlarging to 12 feet at a point 24 feet above the base and again contracting to 4 feet at the base. These are drawn from a chute by use of a swinging gate or apron. Coal and rock are charged in alternate layers. About a week suffices for the passage through the kiln of any particular mass of material. These small kilns produce about 100 to 125 barrels (265 lbs. each) of cement per day.

The larger kilns are 54 feet from extreme base to top. Viewed from the outside they appear to be cylinders 54 feet high and 16 feet in diameter. Their interior space, however, is 10 feet in diameter at the top, enlarging to 12 feet at a point 18 feet above the base. Below this level, though the interior walls still slope outward, the space is really contracted by the occurrence of a conical mass of brickwork in the center of the kiln. This cone throws the downcoming clinker toward the draw-gates at the sides. A 9-inch lining of fire-brick is set around the kiln space proper. This is followed by 9 inches of common brick, and the space between the common-brick lining and the exterior kiln shell (which is $\frac{1}{4}$-inch iron) is filled with clay. A kiln of this size and type will produce 150 barrels of cement per day.

FIG. 42.—Kilns and kiln-housing, Speed plant, Speeds, Ind.

The coal used in these kilns is bituminous nut and slack mixed from Pittsburg or Jellico. About 25.6 lbs. of coal are required to burn a barrel of cement (265 lbs.), equivalent to a fuel consumption of about 9.5 per cent on weight of cement produced.

In the Rosendale district cylindrical kilns are used. These vary from 8 to 12 feet in diameter and from 20 to 36 feet in height. A kiln fed with one half ton of anthracite, pea size, will give 75 to 80 barrels of cement per day. This is equivalent to a fuel consumption of about 7 per cent on the weight of cement produced. From one fifth to one third of the total produce of the kiln may be overburned clinker or underburned rock. This item, however, depends largely upon the skill of the burners, though it is also affected by uncontrollable factros, such as temperature, weather conditions, force, and direction of the wind, etc.

The kilns in use in the Utica district in Illinois are elliptical in cross-section (plan), with vertical walls. The largest kilns of this type are 30 feet in their longest inside diameter and 12 feet wide. Their total height with foundation is 50 feet, giving a clear height of 45 feet from bottom of draw-hole to top of kiln. These kilns turn out 400 barrels (265 lbs. each) of cement per day, taking 18 to 20 lbs. of coal per barrel of cement. This corresponds to a fuel consumption of only 6.8 to 7.5 per cent.

The second size of Utica kilns is 20 feet by 9 feet in its inside diameters. The smallest size is, like the others, elliptical, with inside diameters of 14 and 7 feet, respectively, and a height of 32 feet from top of bridge wall to top of kiln. These kilns turn out 300 to 375 barrels per day.

All the diameters quoted above are internal measurements. The kiln-shell proper is of ¼-inch sheet iron. This is lined, successively, with an 18-inch layer of ashes, 18 inches of stone or common brick, and 9 inches of fire-brick.

The kilns in the central New York district are described * as egg-shaped, 10 feet in diameter at the top, 12 feet at the middle, and 3½ feet at the bottom, with a height of 28 to 42 feet. "There are usually several kilns built together in an embankment of very heavy masonry, so constructed against a hillside that the raw material can be conveniently conveyed there from the quarry and the burned cement easily removed from the bottom of the kiln." The kilns are built of limestone and lined either with sandstone or fire-brick. "When a kiln is ready to be filled a cord of dry, hard, 4-foot wood is put into the bottom and covered 4 inches deep with coarse anthracite coal, then a layer 1 foot thick of cement rock, succeeded by another layer of coal

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* Luther, D. D. The Economic Geology of Onondaga County, New York. 15th Ann. Rept. N. Y. State Geologist, vol. 1, pp. 241–303. 1897.

partly coarse and partly fine. This is repeated till the kiln is filled to the top, which required about 10 tons of coal and 15 cords of stone, equal to 1500 bushels of cement. Then the fire is started at the bottom and gradually works its way upward until the whole mass is glowing with heat. After two or three days the gate or door in the bottom is opened and through it the burned cement rock is drawn to the amount of 250 to 300 bushels per day, fresh coal and rock being constantly added to keep the kiln full to the top. One cord of cement rock makes 100 bushels of cement."

Ries states that two types of kilns are in use at the Cummings plant at Akron, Erie County, N. Y. Of seventeen kilns in use there at the time of his visit, eight were of rectangular cross-section, 9 by 22 feet in area, with a height of 34 feet. The remaining nine were circular in cross-section, with a diameter of 9 feet and a height of 34 feet.

Two types of kilns are in use in the Fort Scott district, Kansas. The more common type is cylindrical, 10 to 12 feet in diameter and 30 to 40 feet in total height. The lower 10 feet or so is of stone, on which is set the kiln proper. This is constructed of $\frac{1}{16}$-inch sheet iron, lined with successive layers of coal ashes, clay, common brick and fire-brick. These kilns are drawn daily, and yield 60 to 75 barrels of cement each per day. The fuel used is slack coal, either Arkansas semi-bituminous from Poteau or Huntingdon or a very sulphurous local coal which underlies the cement rock at Fort Scott. The coal is fed with the rock, and is used at the rate of 30 to 35 lbs. per barrel of cement, equal to a fuel consumption of 11.3 to 13.2 per cent on the weight of cement produced. At a three-kiln plant the burning is managed by five men—two feeding and three drawing the kilns.

At one of the Fort Scott plants four flame-kilns are also in use. These have separate fireplaces, so that the fuel and cement do not come into contact. Lump coal must be used for these kilns, and they are said to be more expensive, both in labor and fuel, than the type above described.

The kilns at the plant of the Howard Cement Company, in Georgia, are of the familiar dome type commonly used in lime and natural-cement burning, and are six in number. Four are jacketed with steel and lined with fire-brick, the space between the jacket and the lining being filled with clay. The two remaining kilns differ from these only in the fact that in place of the steel jacket their exterior surfaces are laid up with rock. These rock-jacketed kilns are said to be somewhat more satisfactory than those of the steel-jacketed type.

All the kilns are 25 feet in height and have an output of 60 barrels of cement each. The kilns are charged to the top with fuel and cement rock, in the proportion of about 300 lbs. of fuel to 2500 lbs. of rock. The fuel used is coal, the sizes being nut, pea, and slack in about equal amounts. Seven or eight days are required, on the average, to "turn a kiln", including charging, burning, and drawing. This corresponds to a fuel consumption of about 18 per cent on the weight of cement produced. In explanation of this high fuel account the reader is referred to the discussion on page 224, where it is shown that the amount of fuel used necessarily increases with the percentage of lime and magnesia. A high-limed cement—and the Howard cement is exceptionally high in lime—therefore requires a very high fuel consumption.

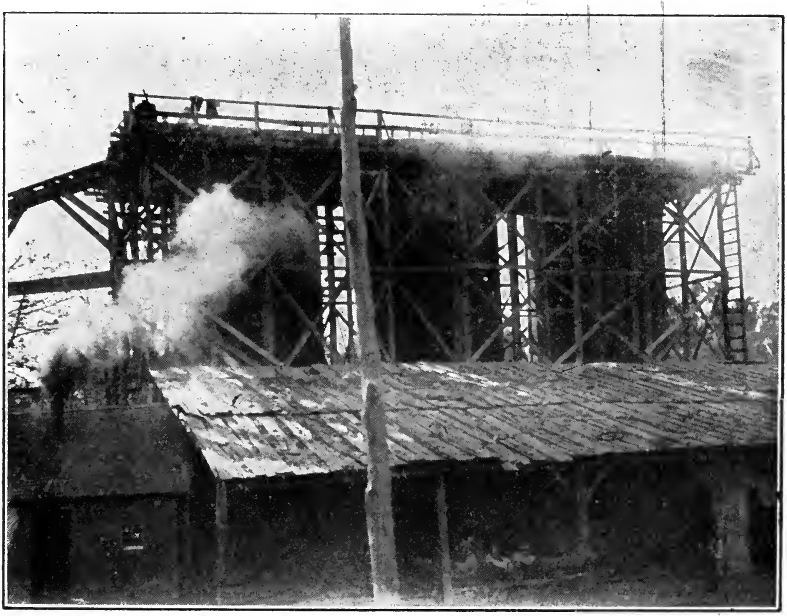

FIG. 43.—Kilns and loading-tracks, Fort Scott, Kan.

Fuel consumption.—The fuel consumption in natural-cement plants is extremely variable, as is shown by the results tabulated below. The variation is caused in some parts by differences in kiln management and character of fuel, but more largely to differences in the composition of the cement. The cements of lowest index demand calcination at high temperatures, while those of high index may be burned at very low temperature.

TABLE 103.

FUEL CONSUMPTION IN AMERICAN NATURAL-CEMENT PLANTS.

Mill.	Kind of Fuel.	Pounds Fuel per 100 Lbs. Cement.
A	Bituminous nut and slack.	9.5
B	Coke.	10.0–16.7
C	Bituminous nut and slack.	11.3
D	Bituminous slack.	11.3–13.2
E	Anthracite nut.	11.6–16.7
F	Bituminous slack.	15.1
G	Anthracite nut.	17.8
H	Bituminous nut, pea, and slack. .	18.0
I	Anthracite pea.	7.0
J	Bituminous nut and slack.	6.6
K	Anthracite pea and slack.	22.0

Hard and soft clinker.—When a natural-cement kiln is drawn, part of the product will consist of hard, clinkered material, part of softer, porous, moderately burned stuff, and part of cores and masses of practically unburned rock. The relative proportions in which these three grades are present will be determined by the type of kiln and the care with which the burning has been conducted. The differences in burning are of course due to some extent to the fact that the masses of rock fed into the kiln differed among themselves in composition; but they are mostly due to the different extent to which the masses have been exposed to the heat of the fuel.

The facts above stated are obvious enough, and the matter might be passed over without further notice if it were not the case that with some rocks the clinkered product will give the best cement, while with other rocks the medium-burned part of the product is the best. This fact certainly requires both consideration and explanation.

The facts themselves are beyond question. In the Rosendale district, for example, from 10 to 20 per cent of the output of the kiln is clinkered material. This clinker is thrown away, for experiments have shown that it does not give a cement nearly as good as the moderately burned product. In the Akron-Buffalo district, on the other hand, the hard, clinkered parts of the product are carefully separated and ground; for experience has shown that these clinkers give a much stronger cement than the softer, more porous masses. These separate facts have been noted by many writers, but no explanation has been offered.

The following seems to explain the difference in practice satisfactorily. It has been noted above that the lower the Cementation Index the higher the temperature necessary to secure perfect combination of the lime and clay. The Rosendale rock, where the Cementation Index averages around 1.50, will therefore be properly burned at a much lower temerature than the Akron rock, where the index falls below 1.10. But a low temperature means low fuel costs, and so there is not the temptation to economize on fuel in burning a rock of high index that there is in burning one of low index. When rocks of high index are burned, therefore, the temperature and the fuel supply will often be allowed to exceed their proper amount, resulting in the production of clinkered material which has been burned higher than was necessary and is therefore inferior. But in burning a rock of low index, it will be necessary to almost clinker the material before perfect combination is secured. Because of the natural tendency to economize on fuel, the temperature will usually be carried a little lower than is necessary. The result is that in burning rocks of low index the clinkered material is correctly burned and gives the best cement, while the softer masses are really underburned and therefore inferior.

The respective values of the hard and soft parts of the product will therefore depend on the Cementation Index. The following seems a fairly satisfactory statement of the case.

(*a*) When burning a product having an index lower than 1.10, the clinkered portions will furnish the best cement. If separated and ground to proper fineness, they will give a cement approximating to Portland in its physical properties.

(*b*) When burning a product where the index is between 1.10 and 1.25, the clinkered portions and the softer masses will probably be of almost equal value.

(*c*) When burning a product where the index is above 1.25, the clinkered portions may be rejected as worthless; and when the index rises above 1.60, even some of the softer masses may be overburned, unless the temperature be kept sufficiently low.

Seasoning and slaking.—It is obvious that in burning a natural rock in a kiln whose temperature cannot be controlled closely, there are opportunities for great differences between the degree of burning which the rock should have received and the degree which it actually does receive. When the Cementation Index of the product is very high—over 1.60 for example—even a light burning will suffice to decarbonate all of the limestone and to secure combination of the lime with the clayey matter. This is especially true if the silica is comparatively low and the alumina and iron oxide high. A rock of this general type can therefore vary quite widely in composition and degree of burning without running any risk of turning out an unsound product.

As the percentages of lime and magnesia rise, however, the problem becomes more difficult, and when the index falls below 1.20 a comparatively slight variation in the composition of the rock or in the degree to which it is burned is apt to give a product containing too much free lime for safety.

When this condition—the presence of free lime or magnesia in the product—occurs frequently, the manufacturer has three options. He may (1) burn at a higher temperature, (2) look for a lower-lime rock, or (3) slake the free lime in some way. The first choice would usually be the best, but in nine cases out of ten the manufacturer will take the third, as being apparently the cheapest.

Free lime in a natural cement may be neutralized either by aerating the ground cement or by sprinkling or steaming the unground clinker. When aeration is practiced, the ground cement must be exposed to the air as freely as possible. This implies that it should be spread out, rather than placed in deep bins, and consequently requires considerable floor-space and manual labor. Steaming or sprinkling the unground clinker requires less space and labor, but care must be taken that excess of steam or water is not allowed to reach the cement. The ideal aimed at is to supply sufficient moisture to slake the free lime, but to leave the aluminates and silicates untouched. Simple storage of the clinker, with free access to the air, will often accomplish this result. An incidental benefit to the manufacturer which comes from slaking the clinker (either by steaming, sprinkling, or storage) lies in the fact that the lime in slaking helps to disintegrate the clinker and thus reduce the cost of grinding.

Grinding the Clinker.

When natural cement was first manufactured in this country, the millstones used at flour-mills were the only available fine grinders. Grinding practice at natural-cement plants was therefore soon established in a form which has persisted at many plants to the present day. Even now a few small plants, I believe, grind natural cement and flour in the same building at different times of the year.

Until quite recently, grinding practice was almost uniform. The burned rock was sledged if necessary, fed through a cracker or other comparatively coarse reducer, and finished on millstones of one type or another. Within the past few years modern grinding machinery has been introduced at a few plants and has given such satisfactory results that no natural-cement manufacturer can afford to disregard the innovations.

The gain in strength due to increased fineness of grinding is well shown by the following data, for which I am indebted to the Western Cement Company, of Louisville, Ky. A year or two ago this company replaced millstones in one of its best plants by tube mills, and increased the fineness from about 76 per cent through a 100-mesh sieve to about 90 per cent through 100-mesh. With mortar briquettes, 1 cement and 2 sand, this gave the following results:

Fineness through 100-mesh.	7 Days.	28 Days.
76 per cent	63 lbs.	124 lbs.
90 " "	128 "	188 "

Actual mill equipments.—The variations in practice which now exist can best be understood by reference to the following data on the actual equipments of a number of the best American mills:

Mill 1.	*a.*	1 Gates crusher	1500 bbls. per day.
	b.	2 Lindhard kominuters	
	c.	2 Davidsen tube mills	
Mill 2.	*a.*	5 McEntee crackers	1600 bbls. per day.
	b.	16-run Esopus millstones	
Mill 3.	*a.*	1 coarse pot crusher	200 bbls. per day (run only about one third time).
	b.	1 fine pot crusher	
	c.	1 Williams mill	
Mill 4.	*a.*	1 Williams mill	100 bbls. per day.
	b.	1 16-foot Bonnot tube mill	
Mill 5.	*a.*	Sturtevant crushers.	
	b.	Cummings grinders.	
	c.	10-run millstones, iron plates.	
	d.	10-run Esopus millstones.	
Mill 6.	*a.*	Pot crushers.	
	b.	Esopus millstones.	
Mill 7.	*a.*	1 Gates crusher	800 bbls. per day.
	b.	2 dry-pans	
	c.	1 Davidsen tube mill	
Mill 8.	*a.*	1 pot crusher	500 bbls. per day.
	b.	1 Williams mill	
Mill 9.	*a.*	Stedman disintegrators.	
	b.	Griffin mills.	

Types of grinding machinery employed.—In Chapter XXXV, where the crushing and grinding machinery used in Portland-cement plants is described in detail, a classification of these machines is introduced as a guide to the descriptions of individual machines. As all but one of the groups there distinguished are represented by one or more machines used in natural-cement mills, the same grouping will be used in the present chapter. It is as follows:

Class 1. JAW CRUSHERS; material crushed between two jaws which approach and recede..................................BLAKE CRUSHER.

Class 2. CONE GRINDERS; material crushed by revolution of a toothed cone or spindle within a toothed cup........GATES CRUSHER, CRACKERS.

Class 3. ROLLS; material crushed between two or more plain, fluted, or toothed cylinders revolving in opposite directions.

Class 4. MILLSTONES; material crushed between two flat or grooved discs, one of which revolves.
MILLSTONES, BUHRS, STURTEVANT EMERY MILL, CUMMINGS MILL.

Class 5. EDGE-RUNNERS; material crushed in a pan under a cylindrical turning on a horizontal axis and gyrating about a vertical axis.
EDGE-RUNNERS, DRY-PANS.

Class 6. CENTRIFUGAL GRINDERS; material crushed between rollers and an annular die, against which the rollers are pressed by centrifugal force.
HUNTINGDON MILL, GRIFFIN MILL, NAROD MILL, CLARK PULVERIZER.

Class 7. BALL GRINDERS; material crushed by balls or pebbles rolling freely in a revolving horizontal cylinder.
KOMINUTER, BALL MILL, TUBE MILL.

Class 8. IMPACT PULVERIZERS; material crushed by a blow in space delivered by revolving hammers, bars, cups, or cages.
WILLIAMS MILL, RAYMOND PULVERIZER, STURTEVANT DISINTEGRATOR, CYCLONE PULVERIZER.

Jaw crushers.—So far as known to the writer no jaw crushers of the Blake type are at present used in natural-cement plants. At one plant, and possibly at others, the Sturtevant roll-jaw crusher is in use as a preliminary reducer on clinker.

Cone grinders.—Though the heavier crushers of this class, such as the Gates crushers, are used at but few natural-cement plants, the group includes a series of machines which have always been held in favor as preliminary reducers on natural-cement clinker—the so-called "crackers".

The "crackers" so extensively used in the natural-cement industry, of which the McEntee cracker of the Rosendale district may be taken as typical, differ but little in design. They consist, as shown in Fig. 44, of two concentric cone-shaped castings, both provided on their adjacent surfaces with a series of grooves and flanges. Gillmore states* that the elements of the lower portions of both cones make a smaller angle with the common axis than the elements of the upper portions, with a view to lessen the strain and the effects of sudden shocks on the machinery by securing a more gradual reduction of the stone to the required size. These lower portions, being subject to very rapid wearing, are made of chilled iron, and are moreover cast in separate pieces, in order that they may be replaced by new ones as occasion requires. The greatest diameter of the core at the top, including the flanges, is 9 inches, at the bottom 5½ to 6 inches, and its height is 15 or 16 inches. The diameter of the shell, measured within the largest flanges, is 14 to 15 inches at the top and a trifle greater than that of the core at the bottom, while its height is 16½ to 18 inches. One cracker of this size, working with a velocity of 80 to 85 revolutions per minute, is sufficient for a mill grinding 250 to 300 barrels per day. It is customary to provide one cracker for every two run of millstones. In the data given on page 237 it will be noted that each of the heavier McEntee crackers now in use is expected to supply three run of millstones.

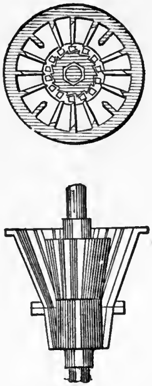

Fig. 44.—Sections of cracker used in grinding natural cement. (After Gillmore.)

Rolls.—Rolls are not used in any American natural-cement plant.

Millstones.—This group includes a series of mills very important in natural-cement practice. The ordinary millstones and buhrstones have been used in this industry since its commencement in 1818, while the Sturtevant "rock-emery" mill and the Cummings grinder represent modern types.

Ordinary millstones are cheap in first cost, but require considerable attention for dressing, etc. They vary in diameter from 3 to 5 feet, and will grind from 6 to 10 barrels of cement per hour to a fineness of 90 per cent through 50-mesh. When greater fineness is required, however, millstones cannot do the work economically.

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* "Limes, Hydraulic Cements, and Mortars", p. 160.

In the Sturtevant rock-emery mill the ordinary millstones or buhrstones are replaced by a "rock-emery" stone. This is composed of a circular iron cup or shell. The center of the circle is made up of a disc of buhrstone while the portion nearer the rim is set with slabs of "rock emery" cemented by metal poured in while molten. Radial strips of buhrstone are set so as to continue the furrows of the central buhrstone to the rim of the wheel. This is shown in Fig. 46. The

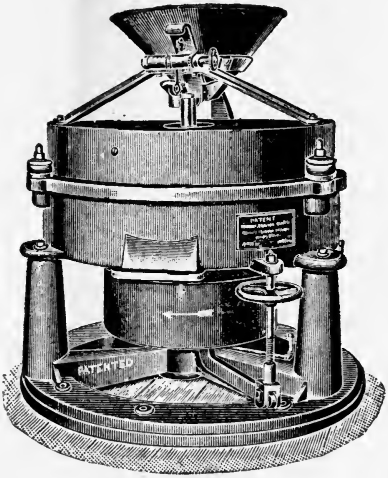

FIG. 45.—Sturtevant horizontal rock-emery mill.

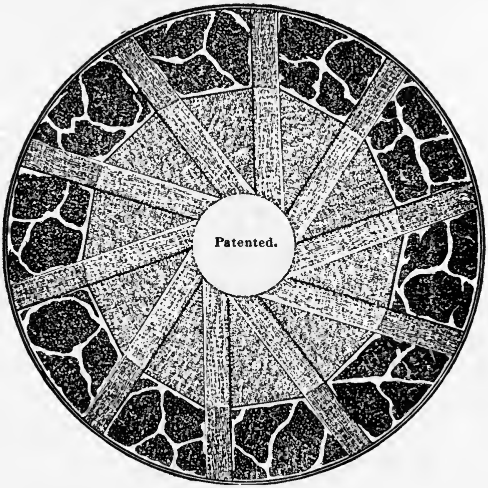

FIG. 46.—Sturtevant rock-emery millstone.

idea is to prevent unequal wear, for in an ordinary millstone the rim wears much faster than the central area. These rock-emery millstones are listed by the manufacturers at the following prices per pair, f. o. b. Boston:

30-inch.	$100
36- "	150
42- "	200
48- "	250
54- "	300

The Sturtevant rock-emery mill itself, which uses the stones above described, is made both as a vertical and horizontal mill, the latter being preferable for harder work. The horizontal mill is shown in Fig. 45, and a section of it is given in Fig. 47. It is made only in 42-inch size, with under-runner stone. The running stone, the under one in this mill, is rigidly fixed to the head of the large vertical shaft, which is made to revolve by a pulley placed on it below the millstones.

A mill of this size will grind from 15 to 20 barrels of cement per hour, taking 15 to 20 H.P. in doing so.

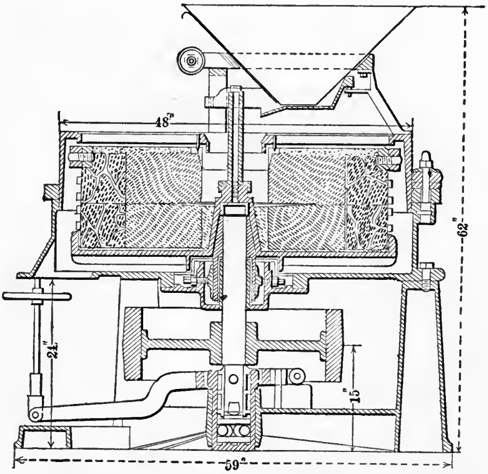

Fig. 47.—Section of Sturtevant horizontal mill.

The Cummings grinder * crushes material between two vertical chilled-iron discs, one of which is stationary, while the other is revolved at high speed. The faces of both discs are cut into a series of bands

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* Ball, C. M. The Cummings ore-granulating mill. Trans. Amer. Institute Mining Engrs., Vol. 21, pp. 516–519. 1893.

and furrows, and the material fed between them is disintegrated rapidly. It is stated that this mill, when working on hard natural-cement clinker, has given very satisfactory results. "The clinker is fed to the mill broken to about the size of 1-inch cubes, and is reduced to about the size of wheat, and from that down to dust, at the rate of 20 tons per hour. This work requires 50 horse-power. In a trial this mill has reduced natural cement (taken direct from the kilns, with the softer portions mixed with the clinker, the latter amounting to about one third of the total) at the rate of 1300 lbs. per minute, the product passing 50-mesh wire screens. The cost of renewal of the grinding plates has been $10 per month, no other repairs being necessary". Using the data above quoted as bases for calculation, it may be seen that the Cummings grinder, when used as a coarse reducer, taking material of 1 inch size and reducing it to, say, $\frac{1}{16}$ inch, requires 2.7 H.P. hours per barrel (300 lbs.) cement. When used as a complete grinder, taking coarse clinker and reducing it all to pass 50-mesh, it requires 5.2 H.P. hours per barrel of cement.

Though no direct statement is made by Mr. Ball, it is perhaps fair to assume that the trial noted above took place at the mill of the Cummings Cement Company in Akron, N. Y. The following description of the reduction practice there will, therefore, be of interest in this connection. It must be recollected that the cement rock of western New York is of very low index, and that the hard, clinkered portions are therefore very valuable when ground.

The crushing practice at the Cummings plant at Akron, N. Y., is stated by Ries * to include the following processes:

"At this works a general system of reduction is used, consisting of (1) Sturtevant crushers; (2) Cummings pulverizers; (3) ten run of 42-inch under-runner millstones faced with chilled-iron plates; (4) ten run of 42-inch Esopus under-runner millstones. The material as it is conveyed from one to another of these sets of crushers is made to pass over screens, whereby such material as has been reduced to proper fineness is separated from the mass and is spouted to a general conveyor, which finally receives the product from all the grinding machines and conveys it to the packing-house " Each set of crushers, while it furnishes a certain percentage of finished product, reduces the entire material to such a degree that what is fed to the fourth series is about the size of wheat-kernels and very hard to reduce. These harder-

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* Ries, H. Lime and cement industries of New York. Bull. 44, New York State Museum, pp. 836, 837.

burned portions make a cement which has a much higher tensile strength than the normally burned product.

Edge-runners.—Dry-pans are in use at only one natural-cement plant, where they take a moderately soft clinker from the crusher and prepare it for the tube mill. Two dry-pans are in use, taking about 15 H.P. each and handling about 400 barrels each per day of ten hours, equivalent to a power requirement of about 0.4 H.P. hour per barrel of cement.

Centrifugal grinders.—Two machines of this type, the Grffiin mill and the Clark pulverizer, are in limited use in the natural-cement industry.

The Clark anti-friction pulverizer has been supplied to two of the plants of the Louisville district for use as an intermediate reducer.

The Griffin mill, described with illustrations on pages 440–443, is, to the writer's knowledge, little used in the natural-cement industry. The only instances of its use that have come to his acquaintance are in grinding the hard portions of the clinker produced at a natural-cement plant in western New York and as an intermediate reducer in one of the mills of the Louisville district.

Ball grinders.—This group includes three very important and efficient machines, the kominuter, the ball mill, and the tube mill. All three of these are now in operation in one important natural-cement district, and all have proven satisfactory, though in different degrees. As these mills are described in detail and figured on pages 447 to 465, nothing need be said here in regard to their construction or general methods of operation.

In handling natural-cement clinker, certain things seem to have been firmly established by the experience of the district above alluded to. These facts may be summarized as follows.

The tube mill, applied to the reduction of natural cement, is an unqualified success. When working on this material its output is very large, while its repairs and wear of pebbles are trifling. The kominuter, highly efficient in actual grinding, formerly gave some trouble in regard to repairs of certain parts, but these defects have now been remedied. The ball mill is also efficient as regards output and power, but is much worse than either kominuter or tube mill as regards repairs.

Two Lindhard kominuters were run for 13½ months on a rather hard-burned natural-cement clinker, during which time they turned out "considerably over" 400,000 barrels of cement. The repair expenses for the same period amounted to $300.18, which includes the cost ($182.70) of one extra set of unused screen frames.

Two Davidsen tube mills, running on natural-cement clinker for twenty-six months, turned out 694,522 barrels of cement. During this time nothing was expended for repairs. The mills were only dumped once, and the total loss of screening pebbles amounted to less than one barrel. "The linings, silex and iron, and the bearings were all found in good condition, with little or no wear to speak of."

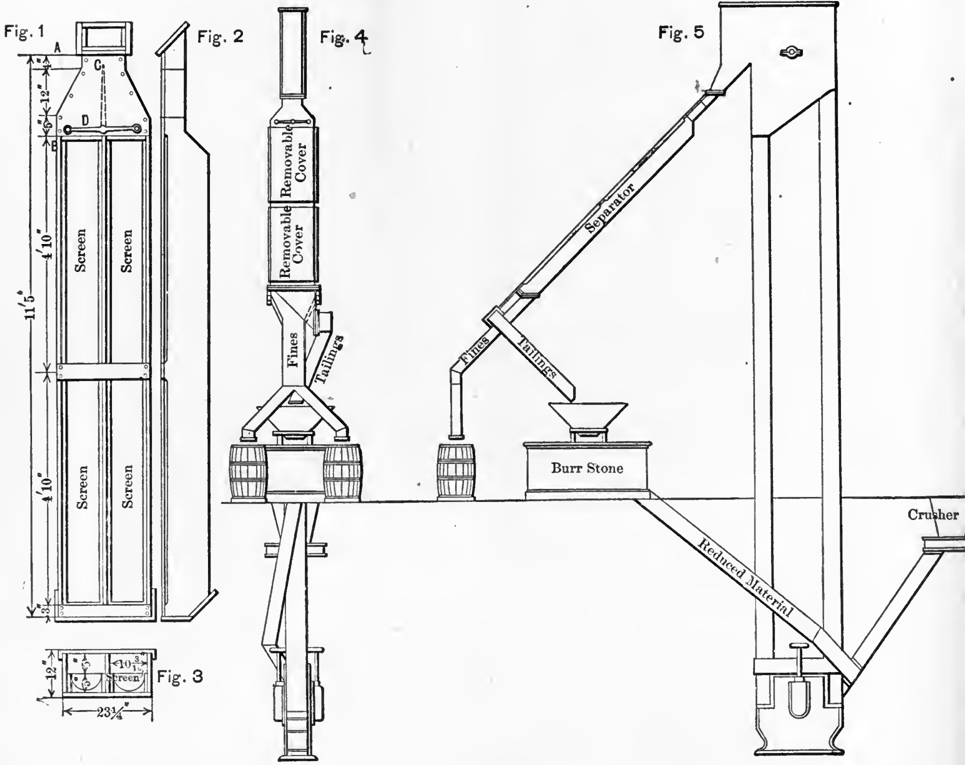

FIG. 48.—Berthelet separator.

1. Top view of separator with covers removed.
2. Side view of separator.
3. Cross-section of separator.
4. Front elevation of separating system installed.
5. Side elevation of separating system installed.

Another pair of tube mills made a similar excellent record in regard to output and repairs.

Impact pulverizers.—The Stedman disintegrator is described and figured on page 36. It is used in at least one natural-cement plant as a preliminary reducer on hard, partly clinkered material.

The Williams mill, which is a high-speed pulverizer in which revolving hammers accomplish the reduction, is described in detail on page 466, with illustrations. It is in use in at least three natural-cement plants to the writer's knowledge. In two of these, at Fort Scott, Kan., it is employed as a final reducer, taking a medium soft clinker from pot crushers and reducing it to pass 50-mesh. In this work it is finishing 50 to 75 barrels (265 lbs. each) of cement per hour. At the Pembina plant in North Dakota the Williams mill is used as a preliminary reducer, to prepare the material for the tube mill. In this work, which is on very hard clinker, it is handling about 20 barrels per hour.

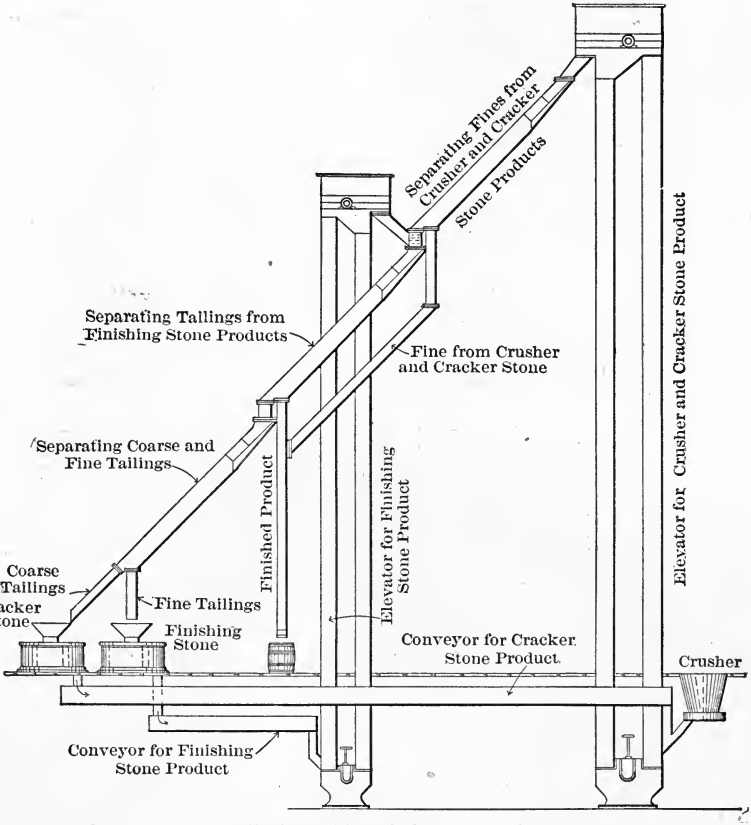

FIG. 49.—Installation of Berthelet separating system.

Separating systems.—The use of separators in the grinding department of a natural-cement plant greatly decreases the power consumption per ton of cement.

The objections to the use of separators in Portland-cement plants do not hold with regard to natural-cement mills, for in grinding natural cement separation does not destroy the homogeneity of the product.

The most effective separating system seen in operation is the Berthelet, first used at the mills of the Milwaukee Cement Company and now installed at many other plants. Sections of a Berthelet separator are shown in Fig. 49, while examples of installation of this separator are shown in both Figs. 48 and 49.

Power required in grinding.—The total horse-power hours required for crushing and grinding a barrel of natural cement will depend on (*a*) the hardness of burning, (*b*) the fineness of the product, and (*c*) the character of the machinery used.

In the table below are given the H.P. hours required to mill a barrel (280 lbs.) of natural cement at eight leading plants. The conditions which affect the power are also briefly noted.

TABLE 104.

POWER REQUIRED IN GRINDING NATURAL CEMENT.

Mill.	H.P. Hours per Barrel (280 Lbs.) Cement.	Burning.	Product.	Milling Machinery.
1	1.5	Fairly hard	Medium	Crushers and millstones *
2	2.3	Medium	Fine	Dry-pan and tube mills
3	2.7	Very light	Fine	Crackers and tube mills
4	2.2	Medium	Fine	Kominuter † and tube mills
5	3.5	Fairly hard	Medium	Crackers and millstones
6	2.9	Medium	Medium	Crusher and Williams mill
7	5.25	Very hard	Very fine	Williams mill and tube mill
8	5.2	Very hard	Fine	Cracker and millstones

* Excellent separating system.
† Not run to full capacity.

Fineness actually attained.—Until quite recently the grinding of an American natural cement was rarely carried further than was necessary to pass 95 per cent of the material through a 50-mesh sieve. There was no particular demand from the engineers for a more finely ground natural cement, and most of the manufacturers merely lived up to the requirements of the average specification. These latter varied considerably, as may be seen from the following table, but in only a few cases was a greater fineness demanded than 85 per cent through a 100-mesh sieve.

The average requirements, then, were low, and the average cement just about passed the requirements. In some cases, however, a higher standard was maintained by the cement manufacturer than by the engineer. The "improved" natural cements of the Lehigh district, most of which are made by mixing Portland and natural cement in various proportions, naturally showed the effect of the very finely ground Portland, and at a few other plants rather fine grinding was practiced.

TABLE 105.

FINENESS REQUIRED BY VARIOUS SPECIFICATIONS.

Specification.	Per Cent Required to Pass.		
	50-mesh.	100-mesh.	200-mesh.
Engineer Corps, U. S. A., 1901.	..	80	
New York State Canals, 1896.	90	80	
Rapid Transit Subway, New York City, 1900–1901	95	85	
Philadelphia Dept. Public Works, 1893.	96		
" " " " 1894, 1895.	99	85	60
" " " " 1896, 1897.	99	90	70

The figures given below represent the results obtained * by very careful sizing of three different brands of natural cements. In making these tests Mr. Bleininger used sieves for the coarser sizing and a washing method for the finer work.

TABLE 106.

FINENESS OF THREE BRANDS NATURAL CEMENT. (BLEININGER.)

No.	Reduced on	Residue on 80-mesh Sieve.	Residue on 120-mesh Sieve.	Residue on 200-mesh Sieve.	Diam. between 0.008 and 0.002 Inch.	Diam. between 0.002 and 0.0002 Inch.	Diam. between 0.0003 and 0.0007 Inch.	Finer than Last Size.	Total Coarser than 200-mesh.
1	Millstones.	7.36	9.93	3.53	16.42	13.98	14.74	34.04	20.82
2	Tube mill.	10.53	12.85	8.50	11.39	22.15	20.72	13.85	31.89
3	Millstones.	12.50	11.59	4.29	16.52	21.95	17.42	15.76	28.37

Within the past few years some natural-cement manufacturers have realized that if the natural-cement industry is to be maintained in the face of competition from Portland cement the product must be improved. One of the easiest methods of doing this is to increase the fineness of the grinding. This has the effect of making the cement more sound and of increasing its sand-carrying capacity, and therefore its strength when tested as mortar.

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* Transactions American Ceramic Society, vol. 5, p. 100.

Packing weights.—In packing natural cements several different standards of weight are in existence in various localities. In the Rosendale, Howe's Cave, and Akron districts the standard barrel weighs about 320 lbs. gross or 300 lbs. net. In the Lehigh district of Pennsylvania the gross and net weights are usually 300 and 280 lbs. respectively. In the Louisville, Utica, Milwaukee, Fort Scott, and other western districts the standard is a barrel weighing about 285 lbs. gross or 265 lbs. net. The recent specifications of the American Society for Testing Materials require packing in bags of 94 lbs., three bags to a barrel.

Exceptions to these general rules occur. The Howard cement of Georgia is naturally so low in specific gravity that an eastern natural-cement barrel will contain only about 240 lbs. of Howard cement. The Pembina cement of North Dakota is, on the other hand, packed at the regular Portland weight of 380 lbs. net per barrel.

Costs of Manufacture.

The items which go to make up the total costs of natural-cement manufacture are (*a*) cost of quarrying or mining the rock, (*b*) cost of labor at kilns and mill, (*c*) cost of fuel for kilns and power, (*d*) interest, etc., on plant. Many of these points have been touched on in the earlier portions of this and the preceding chapter, and will only be summarized briefly below.

Cost of raw material.—The cost of excavating the raw material has been discussed in a preceding chapter (pages 219–221). In the following estimates the figures there given will be taken as a basis for calculation. It was stated that the cost of raw material, delivered at the kiln, might range from 4 to 13 cents per barrel of finished cement. For our present purposes this range in cost can be decreased somewhat, for at most plants the minimum and maximum limits may be taken as 5 and 10 cents respectively.

Labor costs.—In estimating labor costs it may be accepted for the majority of natural-cement plants that the output will vary between 5 and 10 barrels per day per man employed, counting the men in the mine or quarry as well as those in the mill. As the cost of quarry labor in the present calculation has been already charged against the cost of raw material, the mill force alone should be considered here. Examination of a number of plants proves that the output varies between 12 and 22 barrels per day per man, counting all men employed around the mill and kilns, but excluding quarrymen, miners, and teamsters engaged in hauling rock to the mill.

Fuel costs.—It is probably sufficiently accurate to assume that in the average natural-cement mill the consumption of fuel in the kilns may range from 20 to 65 lbs. coal per barrel of cement. An additional 8 to 20 lbs. of coal will be required to furnish power for grinding and other mill operations. The total coal consumption may therefore vary from 28 to 85 pounds per barrel of cement. In cost coal may easily vary from $1 to $4 per ton, and these figures have been used as the limits in the calculations below.

Total costs per barrel.—Using the above data as a basis, the following estimates of the total costs of manufacture have been prepared.

TABLE 107.

ESTIMATES OF COST OF NATURAL-CEMENT MANUFACTURE.

	Min.	Max.
Rock at mill	$0.05	$0.10
Labor at mill	.06	.17
Coal for kilns	.02	.12
Coal for power	.02	.05
Interest, supplies, etc.	.03	.06
Total	$0.18	$0.50

Though the minimum quoted may seem surprisingly small, it is very close to the actual costs attained in a prominent district. The above costs do not, of course, include the cost of packing materials, though they do include the labor involved in packing. This distinction has been made because barrels and sacks are usually charged for at a sufficient price to give a small profit on their use.

Through the courtesy of the manager, a typical daily cost report of a large American natural-cement plant is presented in Table 108, below. This mill averages 500 barrels of cement per day, employing 60 men in the quarry, kilns, mill and packing-house. The output per day averaged, therefore, about 8⅓ barrels for each man employed. If quarry labor be excluded, the output per day averaged 20 barrels per day for each man employed in kilns, mill and packing-house. The rate of pay is, however, higher than in most mills, so that the total labor costs are rather high.

The total cost of cement-manufacture at this plant is therefore close to 34½ cents per barrel. This includes packing labor, but not cost of sacks or barrels, and makes no allowance for interest charges or for sales and general superintendence. Labor costs, as above noted, are high; and the cement is of low Cementation Index, and therefore requires a very large amount of fuel, averaging about 65 lbs. of coal per barrel.

TABLE 108.

DAILY COST REPORT OF NATURAL-CEMENT PLANT.

				Cost per Day.	Cost per Bbl.
Quarry. . .	Labor	1 foreman at $3.00. . . .	$3.00	$71.39	$0.143
		2 engineers at $2.00. . .	4.00		
		2 drillers at $2.00. . . .	4.00		
		1 blaster at $1.75.	1.75		
		12 rockmen at $1.75. . . .	21.00		
		15 strippers at $1.75. . . .	26.25		
		1 blacksmith at $2.00. .	2.00		
		1 laborer at $1.50.	1.50		
	Materials. .	Explosives.	5.00		
		Coal.	2.50		
		Oil.	0.39		
Kilns. . . .	Labor.	1 engineer at $2.00. . . .	$2.00	$54.65	$0.109
		2 coalers at $2.00, $1.75.	3.75		
		1 carman at $2.00.	2.00		
		3 pitmen at $1.75.	5.25		
		3 loaders at $1.75, $1.50	5.00		
	Materials. .	Coal.	36.00		
		Lights.	.50		
		Oil.	.15		
Mill.	Labor.	2 engineers at $2.00. . .	$4.00	$17.70	$0.035
		2 millers at $2.00, $2.25.	4.25		
		1 carman at $1.50.	1.50		
		1 watchman at $1.50. .	1.50		
	Materials. .	Coal.	5.20		
		Lights.	.50		
		Oil.	.75		
Packing. .	Labor.	1 foreman at $2.00. . . .	$2.00	$16.00	$0.032
		8 spreaders at $1.75. . .	$14.00		
Total costs, excluding packages.				$172.74	$0.345

References on manufacturing methods.—The papers and reports cited below deal largely or entirely with methods and details of manufacture of natural cements. Incidental references of more or less value will also be found in the reports listed on pages 221–222.

Bleininger, A. V. Manufacture of hydraulic cements. Bulletin 3, Ohio Geological Survey. 8vo, 391 pp. 1904.

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Brown, C. C. Directory of American Cement Industries. 3d edition, 8vo, 734 pp. Indianapolis, 1904.

Candlot, E. Ciments et chaux hydrauliques. 2d edition, 8vo, 455 pp. Paris, 1898.

Cummings, U. American Cements. 12mo, 299 pp. Boston, 1898.

Freeman, H. C. The hydraulic cement works of the Utica Cement Company. Trans. Amer. Institute Mining Engineers, vol. 13, pp. 172–181. 1885.

Gillmore, Q. A. Practical Treatise on Limes, Hydraulic Cements, and Mortars. 8vo, 10th edition, 334 pp. New York, 1890.

Lewis, F. H. The natural-cement plant at Speeds, Ind. Engineering Record, Sept. 10, 1898. Reprinted in The Cement Industry, pp. 178–183. 1900.

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Lewis, F. H. The plant of the New York and Rosendale Cement Company, Rondout, N. Y. The Cement Industry, pp. 161–168. 1900.

Lewis, F. H. The plant of the Milwaukee Cement Company, Milwaukee, Wis, Engineering Record, April 2, 1898. Reprinted in The Cement Industry. pp. 169–177. 1900.

Richardson, C. Series of articles in the Brickbuilder, 1897–1898.

Siebenthal. The Silver Creek hydraulic limestone of southeastern Indiana. 25th Ann. Rep. Indiana Dept. Geology, pp. 331–389. 1901.

Anon. The Berthelet separator and the Campbell kiln in cement manufacture. Engineering News, Dec. 23, 1897.

CHAPTER XIX.

COMPOSITION AND PROPERTIES OF NATURAL CEMENTS.

THE preceding chapters will have failed of their purpose if the reader does not now realize that the cements commonly grouped as "natural cements" differ so widely among themselves as to almost prevent *any* general statement being made in regard to the group. These differences have appeared in the composition of the various cement rocks, in the degree of burning to which they were subjected, and in the condition of the mass which resulted from this burning. They will appear still more markedly, however, in the composition and properties of the finished products.

In the present chapter data will be presented bearing on these subjects, but they will be treated as illustrating certain points in connection with the processes of manufacture rather than as guides to the testing or uses of the cements. The chemical composition of the natural cements will first be taken up, after which their physical properties will be noted.

Chemical Composition of Natural Cements.

A large series of analyses of natural cements, both American and foreign, are given in the following tables. For convenience of reference these analyses are given by States arranged in alphabetical order. The Cementation Index has been calculated for a number of these products, and is given in the bottom line of each table.

Georgia.—The two Georgia brands whose analyses are given in Table 112 differ widely in composition and index. The Howard cement is of very low index, much like that from Akron, N. Y., and carries 14 to 20 per cent of magnesia. The Chickamauga cement (Dixie brand) is, on the other brand, of medium high index, and runs very low in magnesia, like the natural cements of the Lehigh district and of France.

Illinois.—The Utica cements are quite close in composition to those from the Rosendale district, N. Y., but run somewhat lower in index.

Indiana–Kentucky.—The Louisville cements are of moderate index and average about 11 per cent magnesia.

TABLE 109.

ANALYSES OF NATURAL CEMENTS, GEORGIA.

	1.	2.	3.
Silica (SiO_2)	22.58	19.60	27.68
Alumina (Al_2O_3)	7.23	11.60	9.10
Iron oxide (Fe_2O_3)	3.35		2.52
Lime (CaO)	48.18	48.86	57.96
Magnesia (MgO)	15.00	18.14	2.52
Cementation Index	1.06	0.895	1.44

1. "Howard". Quoted by Cummings, "American Cements", p. 35.
2. " W. M. Bouron, analyst. Privately communicated.
3. "Dixie". Guild & Co., analysts. Manufacturer's circular.

TABLE 110.

ANALYSES OF NATURAL CEMENTS, UTICA, ILLINOIS.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	19.89	27.60	34.66	35.43	27.00	29.61
Alumina (Al_2O_3)	11.61	10.60	5.10	9.92	2.76(?)	2.34
Iron oxide (Fe_2O_3)	1.35	0.80	1.00		2.16	1.50
Lime (CaO)	29.51	33.04	30.24	33.67	29.99	29.74
Magnesia (MgO)	20.38	17.26	18.00	20.98	19.79	20.81
Alkalies (K_2O,Na_2O)	5.96	7.42	6.16	.....	1.77	n. d.
Carbon dioxide (CO_2)	n. d.	2.00	4.84	.....	15.96(?)	14.97
Water	n. d.					
Cementation Index	1.19					

1. Haas & McGraw, analysts. Engineering News, April 30, 1896.
2. Quoted by Cummings, "American Cements", p. 36.
3. " " " " " "
4. J. V. Blaney, analyst. Trans. Am. Inst. Min. Engrs., vol. 13, p. 180.
5. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.
6. J. W. Skinner, analyst. Privately communicated.

TABLE 111.

ANALYSES OF NATURAL CEMENTS, LOUISVILLE DISTRICT, IND.–KY.

	1.*	2.	3.	4.	5.
Silica (SiO_2)	18.92	21.10	22.54	23.29	24.40
Alumina (Al_2O_3)	11.02	7.50	8.24	5.96	6.20
Iron oxide (Fe_2O_3)	1.91		2.14	2.16	
Lime (CaO)	46.90	44.40	42.31	41.28	41.80
Magnesia (MgO)	0.97†	7.00	5.39	15.39	16.29
Alkalies (K_2O,Na_2O)	n. d.	0.80	2.82	1.98	1.52
Carbon dioxide (CO_2)	n. d.	11.18	n. d.	n. d.	9.89
Water	n. d.	1.16	n. d.	n. d.	
Cementation Index	.....	1.23			

*See next page for references.
†Probably erroneous; omitted in making up average.

TABLE 111.—*Continued.*

	6.	7.	8.	9.	10.
Silica (SiO_2)	25.28	26.40	23.13	24.76	24.16
Alumina (Al_2O_3)	7.85	6.28	7.87	4.78	4.76
Iron oxide (Fe_2O_3)	1.43	1.00	1.73	3.24	3.40
Lime (CaO)	44.65	45.22	43.79	38.28	46.64
Magnesia (MgO)	9.50	9.00	10.43	11.94	12.00
Alkalies (K_2O,Na_2O)	n. d.	4.00	2.22	n. d.	
Carbon dioxide (CO_2) Water	7.04	7.86	9.28	10.39	6.75
Cementation Index	.....	.....	1.28		

1. Quoted by Jameson. "Portland Cement", p. 177.
2. " " Smith. Mineral Industry, vol. 1, p. 50.
3. Haas, & McGraw, analysts. Engineering News, April 30, 1896. "Diamond" brand.
4. " " " " " " " " " "Star" brand.
5. Lord, analyst. Rep. Ohio Geological Survey, vol. 6, p. 674.
6. Quoted by Cummings. "American Cements", p. 35. "Hulme Star" brand.
7. " " " " " " " "Fern Leaf" brand.
8. Average of preceding seven analyses.
9–10. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.

Kansas.—The natural cements from the Fort Scott district of Kansas are quite close in magnesia percentage and index to those of the Louisville district, as can be seen on comparing the analyses given in tables 111 and 112.

TABLE 112.

ANALYSES OF NATURAL CEMENTS, FORT SCOTT, KAN.

	1.	2.	3.
Silica (SiO_2)	23.32	21.80	21.67
Alumina (Al_2O_3)	6.99	4.00	10.85
Iron oxide (Fe_2O_3)	5.97	5.00	3.05
Lime (CaO)	53.96	49.80	49.20
Magnesia (MgO)	7.76	12.16	7.90
Carbon dioxide (CO_2) Water	2.00	4.50	7.27
Cementation Index	1.19		

1. Quoted by Cummings. "American Cements", p. 35. "Brockett's Double Star" brand.
2. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.
3. "Tests of Metals, etc., at Watertown Arsenal", for 1897, p. 403.

Maryland.—The Cumberland and Hancock cements are of particularly high index, carrying large percentages of clayey matter and practically no magnesia.

Minnesota.—Both brands of Minnesota cements are high in magnesia and of very low index.

TABLE 113.

ANALYSES OF NATURAL CEMENTS, POTOMAC DISTRICT, MD.

(Average index, excluding No. 7, = 1.95.)

	1.	2.	3.	4.	5.
Silica (SiO_2)	25.70	28.02	28.30	28.36	28.38
Alumina (Al_2O_3)	12.28	10.20	10.12	9.85	11.71
Iron oxide (Fe_2O_3)	4.22	8.80	4.42	3.07	2.29
Lime (CaO)	52.69	44.48	49.60	45.04	43.97
Magnesia (MgO)	1.44	1.00	3.76	2.82	2.21
Carbon dioxide (CO_2)					
Water					
Cementation Index	1.61	2.09	1.70	1.88	1.99

	6.	7.	8.	9.	10.
Silica (SiO_2)	30.02	36.60	29.74	30.22	29.66
Alumina (Al_2O_3)	13.55	14.58	8.34	8.38	14.76
Iron oxide (Fe_2O_3)	3.00	5.12	4.14	5.38	
Lime (CaO)	44.58	37.50	45.66	39.54	41.96
Magnesia (MgO)	2.76	2.73	2.86	3.80	3.19
Carbon dioxide (CO_2)	.....	.....	8.13	10.20	7.97
Water					
Cementation Index	2.08	2.95	1.92	2.18	2.11

1. Cumberland, Md. A. W. Dow, analyst. Mineral Industry, vol. 6, p. 96.
2. Hancock, Md. Quoted by Cummings. "American Cements", p. 36.
3. Cumberland, Md. A. W. Dow, analyst. Mineral Industry, vol. 6, p. 96.
4. Hancock, Md. " " " " " " "
5. Cumberland, Md. Quoted by Cummings. "American Cements", p. 36.
6. Hancock, Md. A. W. Dow, analyst. Mineral Industry, vol. 6, p. 96.
7. Cumberland, Md. A. W. Dow, analyst. Mineral Industry, vol. 6, p. 96.
8. Hancock, Md. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.

9–10. Cumberland, Md. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.

TABLE 114.

ANALYSES OF MINNESOTA NATURAL CEMENTS.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	21.36	28.43	16.24	18.59	19.02	27.70
Alumina (Al_2O_3)	3.34	6.71	5.35	9.14	8.96	7.06
Iron oxide (Fe_2O_3)	3.80	1.94	4.71	1.00	1.24	1.86
Lime (CaO)	45.51	36.31	38.53	40.70	41.18	37.00
Magnesia (MgO)	15.02	23.89	22.73	27.00	26.58	22.63
Alkalies (K_2O, Na_2O)	2.03	1.80	2.30	n. d.	n. d.	n. d.
Sulphur trioxide (SO_3)	1.94	n. d.	n. d.	n. d.	1.27	1.23
Carbon dioxide (CO_2)	10.00	0.92	9.26	3.57	1.75	2.46
Water			0.51		n. d.	n. d.
Cementation Index	0.994	1.28	0.792	0.800	0.816	1.26

1. Mankato. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229. 1897.
2. " Quoted by Cummings, "American Cements", p. 36.
3. " C. F. Sidener, analyst. 11th Ann. Rep. Minnesota Geol. Survey, p. 179.
4. Austin. Quoted by Cummings, "American Cements", p. 36.
5. " Tests of Metals at Watertown Arsenal, 1901.
6. Mankato. " " " " " " "

New York.—The cements of the Rosendale district are the typical American natural cements, with rather high index, and carrying 15 to 20 per cent of magnesia.

TABLE 115.

ANALYSES OF NATURAL CEMENTS, ROSENDALE DISTRICT, N. Y.

	1.*	2.	3.	4.	5.	6.
Silica (SiO_2)	25.91	27.98	24.30	27.75	30.84	25.92
Alumina (Al_2O_3)	6.20	7.28	7.22	5.50	7.75	9.40
Iron oxide (Fe_2O_3)	3.81	1.70	5.06	4.28	2.11	
Lime (CaO)	34.62	37.59	33.70	35.61	34.49	33.18
Magnesia (MgO)	20.92	15.00	20.94	21.18	17.77	19.61
Alkalies (K_2O,Na_2O)	n. d.	7.96	n. d.	tr.	4.00	n. d.
Sulphur trioxide (SO_3)	n. d.	n. d.	n. d.	0.5	n. d.	n. d.
Carbon dioxide (CO_2)	5.09	2.49	n. d.	4.05	3.04	4.40
Water	2.80		n. d.	n. d.		
Cementation Index	1.29	....	....	1.33		

	7.	8.	9.	10.	11.	12.
Silica (SiO_2)	30.50	30.78	24.42	22.77	29.00	28.91
Alumina (Al_2O_3)	6.84	8.68	8.16	10.43	10.40	10.96
Iron oxide (Fe_2O_3)	2.42		3.96			4.68
Lime (CaO)	34.38	34.14	36.30	34.54	32.35	34.64
Magnesia (MgO)	18.00	19.61	16.93	21.85	19.92	14.82
Alkalies (K_2O,Na_2O)	3.98	1.62	n. d.	3.63	n. d.	1.80
Sulphur trioxide (SO_3)	n. d.	n. d.	n. d.	1.44	n. d.	1.04
Carbon dioxide (CO_2)	3.78	3.57	n. d.	2.84	n. d.	4.50
Water			n. d.	1.59	n. d.	
Cementation Index	....	....	....	....	....	1.74

	13.	14.	15.	16.	17.	18.
Silica (SiO_2)	29.84	27.30	21.73	17.17	27.00	29.98
Alumina (Al_2O_3)	15.20	7.14	11.18	10.80	17.50	6.88
Iron oxide (Fe_2O_3)		1.80	4.14			2.50
Lime (CaO)	35.84	35.98	33.77	48.28	35.35	33.23
Magnesia (MgO)	14.02	18.00	21.20	19.13	14.75	17.80
Alkalies (K_2O,Na_2O)	n. d.	6.80	2.99	tr.	n. d.	7.10
Sulphur trioxide (SO_3)	0.93	n. d.	n. d.	1.20	1.41	n. d.
Carbon dioxide (CO_2)	3.73	2.98	n. d.	3.38	4.68	3.13
Water			n. d.	n. d.		
Cementation Index	1.78	1.39	1.19			

* See opposite page for references.

TABLE 115.—*Continued.*

	19.	20.	21.	22.	23.
Silica (SiO_2)	31.28	22.75	25.00	28.71	26.66
Alumina (Al_2O_3)	11.30	13.40	8.93	5.88	11.48
Iron oxide (Fe_2O_3)		3.30	2.27	3.60	3.02
Lime (CaO)	36.67	37.60	39.30	27.00	38.33
Magnesia (MgO)	14.35	16.65	16.18	30.00	16.41
Alkalies (K_2O,Na_2O)	n. d.	n. d.	n. d.	n. d.	n. d.
Sulphur trioxide (SO_3)	1.32	n. d.	1.40	1.30	1.35
Carbon dioxide (CO_2)	4.27	5.00	2.66	3.52	2.75
Water		1.36	n. d.	n. d.	n. d.
Cementation Index					

1. "F. O. Norton." Private communication.
2. " Quoted by Cummings. "American Cements", p. 35.
3. " Quoted by Lewis. Mineral Industry, vol. 6, p. 96.
4. "Beach's." J. O. Hargrove, analyst. Private communication.
5. "Brooklyn Bridge." Quoted by Cummings. "American Cements", p. 35.
6. " " C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.
7. Newark Lime and Cement Co. Quoted by Cummings. "American Cements", p. 35.
8. Newark and Rosendale. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.
9. "Old Newark." Booth, Garrett, and Blair, analysts. Mineral Industry, vol. 6, p. 96.
10. "Lawrence", Rosendale Cement Co. Mineral Resources U. S. for 1883–1884.
11. Lawrenceville cement. A. W. Dow, analyst. Mineral Industry, vol. 6, p. 96.
12. "Hoffmann", Lawrence Cement Co. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.
13. " " " " " " " "
14. " " " " Quoted by Cummings. "American Cements", p. 35.
15. " " " " Haas and McGraw, analysts. Engineering News, April 30, 1896.
16. "Hoffmann", Lawrence Cement Co. Mineral Resources U. S. for 1883–1884. Very exceptional analysis.
17. "Rock Lock." C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.
18. " " Quoted by Cummings. "American Cements", p. 35.
19. "Hudson River." C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.
20. Rondout, N. Y. L. C. Beck, analyst. "Mineralogy of New York", p. 78.
21. "Hoffmann." } Tests of Metals, etc., at Watertown Arsenal, 1901.
22. "Newark and Rosendale." }
23. "Norton." }

The following analysis is of the natural cement made at Howe's Cave by the Helderberg Portland Cement Company:

ANALYSIS OF NATURAL CEMENT, SCHOHARIE COUNTY, N. Y.

Silica (SiO_2)	26.54
Alumina (Al_2O_3)	5.89
Iron oxide (Fe_2O_3)	
Lime (CaO)	45.30
Magnesia (MgO)	17.06
Cementation Index	1.17

The cements of central New York are of low index, though usually not so low as those of the Akron-Buffalo district.

The natural cements of the Akron-Buffalo district carry usually 20 to 25 per cent magnesia and are of very low index.

TABLE 116.

ANALYSES OF NATURAL CEMENTS, CENTRAL NEW YORK.

	1.	2.	3.	4.
Silica (SiO_2)	20.30	16.56	35.43	24.10
Alumina (Al_2O_3)	13.67	10.77	9.92	11.45
Iron oxide (Fe_2O_3)				
Lime (CaO)	47.48	39.50	33.67	40.22
Magnesia (MgO)	18.55	22.27	20.98	20.60
Cementation Index	.....	.....	.....	1.13

1. Brown Cement Co., Manlius, Onondaga County. W. M. Smith, analyst. 20th Ann. Rept' U. S. Geol. Survey, pt. 6, p. 428.
2. Near Chittenango, Madison County. L. C. Beck, analyst. "Mineralogy of New York", p. 80.
3. South of Utica, Oneida County. Gillmore. "Limes, Cements, and Mortars", p. 125.
4. Average of preceding three analyses.

TABLE 117.

ANALYSES OF NATURAL CEMENTS, AKRON-BUFFALO DISTRICT, N. Y.

	1.	2.	3.	4.	5.
Silica (SiO_2)	17.14	22.62	20.20	22.70	16.48
Alumina (Al_2O_3)	7.61	7.44	4.40	7.40	4.40
Iron oxide (Fe_2O_3)	2.00	1.40	2.80	.....	2.00
Lime (CaO)	36.83	40.68	41.60	36.31	39.20
Magnesia (MgO)	25.09	22.00	22.24	25.72	26.52
Alkalies (K_2O,Na_2O)	3.64	2.23	1.62	n. d.	1.85
Sulphur trioxide (SO_3)	n. d.	n. d.	2.06	n. d.	1.39
Carbon dioxide (CO_2)	n. d.	3.63	6.90	4.00	6.80
Water	n. d.	n. d.		n. d.	
Cementation Index	0.801	0.874	0.871	0.991	0.686

	6.	7.	8.	9.	10.
Silica (SiO_2)	26.69	20.75	22.94	20.40	23.70
Alumina (Al_2O_3)	7.21	10.02	6.30	6.22	16.70
Iron oxide (Fe_2O_3)	1.30		2.90	2.56	3.30
Lime (CaO)	43.12	37.54	43.74	40.64	37.00
Magnesia (MgO)	19.55	26.14	20.72	25.80	15.30
Alkalies (K_2O,Na_2O)	1.13	2.12	n. d.	n. d.	n. d.
Sulphur trioxide (SO_3)	n. d.	n. d.	n. d.	2.91	1.98
Carbon dioxide (CO_2)	1.00	4.58	1.00	1.47	2.00
Water	n. d.		n. d.	n. d.	n. d.
Cementation Index	1.18	0.932	1.006	0.856	2.21

Average index, excluding No. 10. . . . . = .911

$$\frac{\text{Average CaO} = 39.666}{\text{Average MgO} = 22.908} = 1.73$$

1. "Union Akron." Haas and McGraw, analysts. Engineering News, April 30, 1896.
2. "Newman Akron." Quoted by Cummings. "American Cements", p. 35.
3. "Akron Star." C. Richardson, analyst. Brickbuilder, vol. 6, p. 229. 1897.
4. "Buffalo Portland." N. Lord, analyst. Reports Ohio Geological Survey, vol. 6, p. 674.
5. "Buffalo." C. Richardson, analyst. Brickbuilder, vol. 6, p. 229. 1897.
6. "Obelisk." Quoted by Cummings. "American Cements", p. 35.
7. " C. Richardson, analyst. Brickbuilder, vol. 6, p. 229. 1897.
8. "Storm King Portland." Tests of Metals, etc., at Watertown Arsenal, 1901, p.
9. "Akron Star." Tests of Metals, etc., at Watertown Arsenal, 1901, p.
10. "Obelisk." Tests of Metals, etc., at Watertown Arsenal, 1901, p.

North Dakota.—The Pembina cement is a highly satisfactory product, of high index and low magnesia, much like the Chickamauga cement of Georgia.

TABLE 118.

ANALYSES OF NATURAL CEMENT, NORTH DAKOTA.

	1.	2.	3.	4.
Silica (SiO_2).................	24.62	23.60	23.90	24.72
Alumina (Al_2O_3).............	15.12	16.50	15.90	15.00
Iron oxide (Fe_2O_3)...........				
Lime (CaO).................	52.30	51.40	51.40	51.30
Cementation Index..........	1.61			

	5.	6.	7.	8.
Silica (SiO_2).................	24.40	24.40	24.06	24.46
Alumina (Al_2O_3).............	15.26	15.38	15.00	15.30
Iron oxide (Fe_2O_3)...........				
Lime (CaO).................	52.07	51.96	51.96	52.37
Cementation Index..........	.....	.....	1.58	

1–8. Analyses of natural cement, Pembina Cement Co., Milton, N. D.

Pennsylvania.—The Lehigh district natural cements are low in magnesia. As marketed they are often very badly mixed products. Portland cement is usually added, while adulteration with coke and ground limestone is not unknown.

TABLE 119.

ANALYSES OF NATURAL CEMENTS, LEHIGH DISTRICT, PA.

	1.	2.	3.
Silica (SiO_2).............................	18.18	18.28	30.40
Alumina (Al_2O_3).............................	9.78	7.43	10.36
Iron oxide (Fe_2O_3)...........................			2.60
Lime (CaO).............................	69.18	51.53	52.12
Magnesia (MgO).........................	1.98	2.07	0.21
Alkalies (K_2O,Na_2O)....................	n. d.	1.50	n. d.
Sulphur trioxide (SO_3).....................	n. d.	n. d.	1.24
Carbon dioxide (CO_2)......................	n. d.	16.26	3.07
Water..............................	n. d.		n. d.

1. Quoted by Smith. Mineral Industry, vol. 1, p. 50.
2. " " " " " " "
3. "Bonneville Improved." Tests of Metals at Watertown Arsenal, 1901.

West Virginia–Maryland.—These cements are fairly low in magnesia and usually of very high index.

TABLE 120.

ANALYSES OF NATURAL CEMENTS, SHEPHERDSTOWN-ANTIETAM DISTRICT, W. VA.-MD.

	1.	2.	3.
Silica (SiO_2)	33.42	36.51	33.50
Alumina (Al_2O_3)	10.04	9.36	10.44
Iron oxide (Fe_2O_3)	6.00		3.25
Lime (CaO)	32.79	34.83	29.38
Magnesia (MgO)	9.59	11.33	13.37
Alkalies (K_2O,Na_2O)	0.50	1.25	n. d.
Sulphur trioxide (SO_3)	n. d.	1.49	1.15
Carbon dioxide (CO_2)	7.66	5.13	7.15
Water			
Cementation Index	2.35	2.20	2.23

1. Shepherdstown, W. Va. Quoted by Cummings. "American Cements", p 35.
2. Shepherdstown, W. Va. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.
3. Antietam, Md. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.

Wisconsin.—The Milwaukee cements are of quite low index, ranging from 1.10 to 1.20, and carry a little more magnesia than do the Rosendale products.

TABLE 121.

ANALYSES OF NATURAL CEMENTS, MILWAUKEE DISTRICT, WIS.

	1.	2.
Silica $(SiO)_2$	23.16	25.00
Alumina (Al_2O_3)	6.33	4.00
Iron oxide (Fe_2O_3)	1.71	2.80
Lime (CaO)	36.08	33.40
Magnesia (MgO)	20.38	22.60
Alkalies (K_2O,Na_2O)	5.27	2.51
Sulphur trioxide (SO_3)	n. d.	2.59
Carbon dioxide (CO_2)	7.07	9.50
Water		
Cementation Index	1.09	1.17

1. Quoted by Cummings. "American Cements", p. 35.
2. C. Richardson, analyst. Brickbuilder, vol. 6, p. 229.

Belgium.—The manufacture and character of the Belgian natural cements have been described in detail on preceding pages. As marketed they are usually cements of low index (1.05 to 1.15) and carry small percentages of magnesia.

England.—English natural cements are commonly products of high index, carrying much clayey matter, and often containing remarkably high percentages of iron oxide.

France.—The analyses given in Table 124 represent a peculiarly homogeneous group of natural cements, a fact which is brought out clearly when their Cementation Indexes are calculated and compared.

TABLE 122.

ANALYSES OF "NATURAL PORTLAND" CEMENTS, BELGIUM.

	1.	2.
Silica (SiO_2)	22.17	28.0
Alumina (Al_2O_3)	4.60	3.0
Iron oxide (Fe_2O_3)	1.23	2.0
Lime (CaO)	60.86	62.0
Magnesia (MgO)	0.73	0.6
Sulphur trioxide (SO_3)	n. d.	1.2
Carbon dioxide (CO_2)	1.46	1.2
Water	0.48	n. d.
Cementation Index	1.09	1.32

1. Compagnie Générale des Ciments Portlands de l'Escaut, Tournai.
2. Dumon et Cie, Tournai.

TABLE 123.

ANALYSES OF NATURAL CEMENTS, ENGLAND.

	1.	2.	3.	4.
Silica (SiO_2)	24.41	31.36	26.12	25.27
Alumina (Al_2O_3)	9.65	5.01	7.92	7.47
Iron oxide (Fe_2O_3)	18.86	11.74	6.46	9.05
Lime (CaO)	41.36	46.36	56.44	55.65
Magnesia (MgO)	4.73	3.93	1.60	1.59
Cementation Index	1.92	.....	.....	1.48

1. Sheppey. Quoted by Redgrave. "Calcareous Cements", p. 49.
2. Harwich. " " " " " "
3. Whitby. " " Zwick, p. 74.
4. London. " " " "

Germany-Austria.—Analyses of a number of German and Austrian natural cements are given in Table 125. This series includes two interesting analyses (Nos. 5 and 6) of cements of very low index, carrying high percentages of magnesia.

TABLE 124.

ANALYSES OF NATURAL CEMENTS, FRANCE.

	1.*	2.	3.	4.
Silica (SiO_2)	24.94	20.50	21.2	21.82
Alumina (Al_2O_3)	9.00	8.40	6.9	8.88
Iron oxide (Fe_2O_3)	1.16	5.70	13.7	12.47
Lime (CaO)	63.64	52.05	56.6	55.69
Magnesia (MgO)	1.26	0.95	1.1	1.12
Sulphur trioxide (SO_3)	n. d.	2.80	n. d.	n. d.
Cementation Index	1.22	1.32	1.32	1.39

* See next page for references.

TABLE 124.—*Continued.*

	5.	6.	7.	8.
Silica (SiO_2)	23.50	24.25	22.10	22.61
Alumina (Al_2O_3)	12.50	10.00	18.21	19.79
Iron oxide (Fe_2O_3)	3.00	4.00	tr.	tr.
Lime (CaO)	52.50	53.50	55.98	51.63
Magnesia (MgO)	2.50	2.50	0.37	0.37
Sulphur trioxide (SO_3)	1.00	2.00	3.34*	5.60*
Cementation Index	1.46	1.52	1.45	1.63

* Lime sulphate, $CaSO_4$.

1. Vassy. Quoted by Cummings. "American Cements", p. 35. Exceptionally high-limed.
2. " " " Bonnami. "Chaux Hydrauliques", etc., p. 54.
3. " " " Zwick. "Hydraulischer Kalk und Portland-Cement", p. 91.
4. " " " " " " " " "
5. Valbonnais. Slow-setting. Bonnami. "Chaux Hydrauliques", etc., p. 54.
6. " Very slow. " " " " "
7. Porte de France. Quick-setting. Bonnami. "Chaux Hydrauliques", etc., p. 151.
8. " " " Slow-setting. " " " " "

TABLE 125.

ANALYSES OF NATURAL CEMENTS, GERMANY AND AUSTRIA.

	1.	2.	3.	4.	5.
Silica (SiO_2)	28.83	27.88	24.12	23.66	20.80
Alumina (Al_2O_3)	6.40	6.19	6.47	7.24	5.80
Iron oxide (Fe_2O_3)	4.80	4.64	5.28	7.97	1.50
Lime (CaO)	58.38	56.45	59.10	58.88	47.83
Magnesia (MgO)	5.00	4.84	4.98	2.25	24.26
Cementation Index	.....	.....	.....	.....	0.80

	6.	7.	8.	9.	10.
Silica (SiO_2)	22.14	25.00	21.48	26.80	23.67
Alumina (Al_2O_3)	5.75	9.00	6.45	10.30	8.83
Iron oxide (Fe_2O_3)	3.07	4.39	2.80	1.90	5.92
Lime (CaO)	44.22	58.02	56.73	59.80	58.80
Magnesia (MgO)	17.77	1.08	3.04	0.30	0.73
Alkalies (K_2O,Na_2O)	4.72	0.62	.....	0.70	1.22
Cementation Index	1.02	1.39	.....	1.455	1.34

1. Rudersdorf. Michäelis, analyst. Quoted in Wagner's "Chemical Technology", 13th ed., p. 669.
2. Rudersdorf. Quoted by Cummings. "American Cements", p. 35.
3. " " " Zwick. "Hydraulischer Kalk und Portland-Cement", p. 74.
4. Hausbergen. } Michäelis, analyst. Quoted in Wagner's "Chemical Technology", 13th ed.,
5. Tarnowitz. } p. 669.
6. Heidelberg. }
7. Piesting. } Quoted by Zwick. "Hydraulischer Kalk und Portland-Cement", p 74.
8. Haring. }
9. Kusstein. } Quoted by Schoch. "Mortel-Materialen", p. 74.
10. Perlmoos. }

Weight and specific gravity.—The specific gravity of American natural cements appears to be greatly underestimated by most engineering authorities. In a recent report,* for example, it is stated that "natural cement has a specific gravity of 2.5 to 2.8". In reality very few of our American cements ever fall as low in specific gravity as 2.8, and it would be nearer the truth to say that, as a class, the natural cements range between 2.8 and 3.2.

In the following table (126) a number of careful determinations are given, selected from various sources so as to cover as many cement districts and brands as possible.

TABLE 126.

SPECIFIC GRAVITY OF AMERICAN NATURAL CEMENTS.

State.	Locality.	Brand.	Authority.	Specific Gravity
Illinois	Utica........	?	C. Richardson	2.70
Kansas	Fort Scott. . .	?	" "	2.79
Maryland	Cumberland	Cumberland Hydraulic Cement Mfg. Co.	Phila. Cement Tests, 1897	2.90
"	"	Cumberland Hydraulic Cement Mfg. Co.	" " " 1899	2.846
"	"	Cumberland and Potomac Cement Co.	" " " 1899	2.828
"	"	Potomac	Watertown Arsenal, 1901	2.94
"	Round Top.	?	C. Richardson	2.84
"	" "	?	Phila. Cement Tests, 1899	2.922
Minnesota	Austin	....	Watertown Arsenal, 1901	3.15
"	Mankato. .	....	" " 1901	2.93
"	" . .	....	C. Richardson	2.81
New York	Rosendale	?	" "	3.04
" "	"	Hoffmann	Watertown Arsenal, 1901	3.06
" "	"	Norton	" " 1901	3.03
" "	"	Newark and Rosendale	" " 1901	3.06
" "	Akron. . . .	"Storm King Portland"	" " 1901	3.07
" "	"	Obelisk	" " 1901	3.12
" "	"	Star	Phila. Cement Tests, 1897	3.17
Pennsylvania	Lehigh	Coplay improved	" " " 1897	3.00
"	"	" "	" " " 1899	2.96
"	"	Hercules improved	" " " 1897	2.97
"	"	American improved	" " " 1897	3.07
"	"	" "	" " " 1899	3.02
"	"	Bonneville improved	Watertown Arsenal, 1901	2.85

Rapidity of set.—Natural cements are normally much quicker-setting than Portlands, but this rapidity of set may be changed by aeration, the use of plaster, etc., to a very remarkable degree.

In 1894–95 Sabin tested the effect of aeration on the setting time of natural cement, with the following results: †

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* Professional Paper No. 28, Corps of Engineers, U. S. A., p. 11.

† Report Chief of Engineers, U. S. A., 1895, p. 2937.

TABLE 127.

EFFECT OF AERATION ON SETTING TIME OF NATURAL CEMENT. (SABIN.)

No.	Direct from Package.		After 19 Days' Aeration.	
	Initial Set, Minutes.	Final Set, Minutes.	Initial Set, Minutes.	Final Set, Minutes.
1	52	110	54	173
2	50	100	51	164
3	44	100	48	166
4	60	280	100	326
5	101	349	147	306
6	87	1200	130	1241
7	80	1178	122	1233
8	72	1202	125	1227
9	108	1256	202	1221
10	192	1247	234	1216

Effects of gypsum or plaster on natural cements.—Natural cements are affected by the addition of gypsum in regard to setting time and strength in much the same manner as Portland cement would be. The degree to which these effects are produced, for the same percentage of gypsum, depends entirely upon the chemical composition of the respective cements. This fact seems to have been entirely overlooked by experimenters, and in consequence the tests which have been made are deprived of much of their value, because the analysis of the cement is rarely included in the report of the test.

Experiments on the effect of gypsum on the rate of set have been carried out by Sabin,* and the results are embodied in Table 128, below, and are shown diagrammatically in Fig. 50.

TABLE 128.

EFFECT OF PLASTER ON SETTING TIME OF NATURAL CEMENT. (SABIN.)

Brand.	Per Cent Plaster.	Setting Time.	
		Initial, Minutes.	Final, Minutes.
A	0	38	543
"	1	106	414
"	2	107	527
"	3	86	671
"	6	42	632
B	0	93	193
"	1	179	439
"	2	302	592
"	3	295	725
"	6	93	698

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* Report Chief of Engineers, U. S. A., 1895, p. 2938.

From this table it will be seen that the maximum retardation of the initial set took place with both brands when 2 per cent of plaster was used. The final set, however, experienced its greatest retardation in both cases when 3 per cent of plaster was employed.

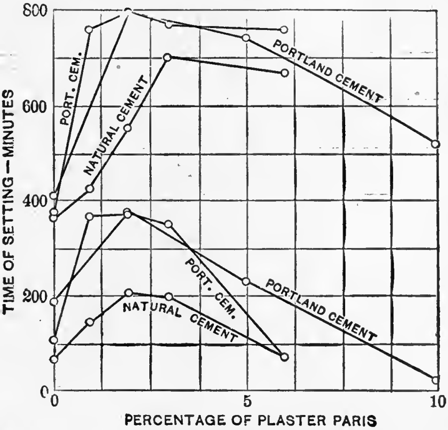

FIG. 50.*—Effect of blasler on setting time. (Sabin.)

Sabin also tested † the effects of plaster on the tensile strength of both neat and mortar briquettes. The results of these tests are shown in the following table (129):

TABLE 129.

EFFECT OF PLASTER ON TENSILE STRENGTH OF NATURAL CEMENT. (SABIN.)

Composition.		Per Cent Plaster.	Tensile Strength, Pounds.		
Cement.	Sand.		7 Days.	6 Months.	1 Year.
1	0	0	146	383	
1	0	1	156	398 [1]	
1	0	2	115 [1]	323	
1	0	3	...	312 [2]	
1	0	6	...	234 [3]	
1	2	0	62	374	448
1	2	1	80	312	395
1	2	2	94	355	408
1	2	3	...	86 [3]	131 [3]
1	2	6	...	151 [3]	107 [3]

[1] Surface cracks. [2] Swelled and nearly disintegrated. [3] Badly cracked and swelled.

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* From Johnson's "Materials of Construction", p. 187.

† Report Chief of Engineers, U. S. A., 1896, p. 2857.

These tests would appear to show that the addition of even 1 per cent of plaster has injurious effects on the soundness of the cement, and less markedly on its tensile strength. Unfortunately, the analysis of the cement tested is not given, and even its name is suppressed, so that the results are less instructive than they might have been.

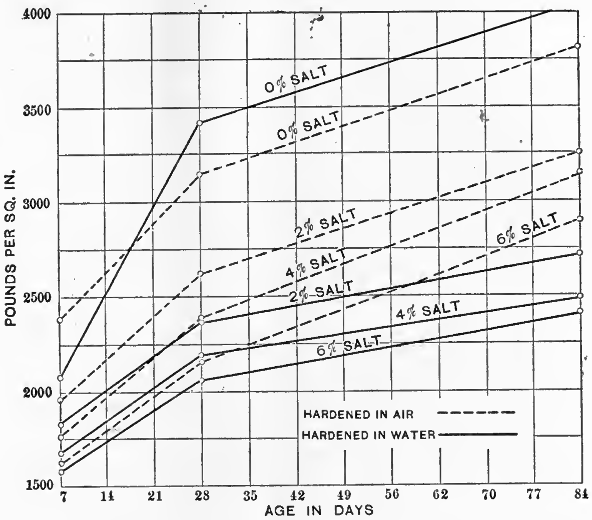

FIG. 51.*—Effect of salt on compressive strength. (Tetmajer.)

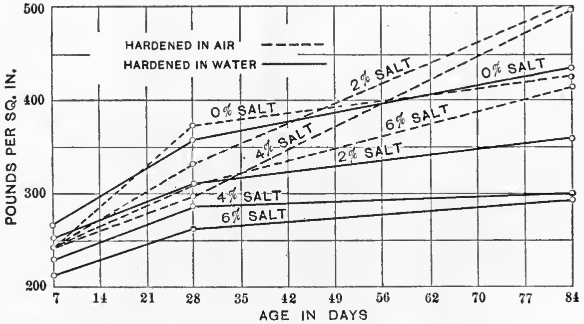

FIG. 52.*—Effect of salt on tensile strength. (Tetmajer.)

In general it may be said that the effects of gypsum or plaster will be directly proportional to the percentage of alumina contained in the cement. This statement has never before been explicitly made,

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* From Johnson's "Materials of Construction", p. 621.

but it is a necessary corollary from recent studies on the behavior of cements with gypsum and in sea-water.

Effect of salt on strength.—In laying masonry in freezing weather it has been customary to specify the use of salt in the water used for the mortar. This lowers the freezing temperature of the water, but does not seem to be of any particular benefit in other respects. It decreases quite markedly the tensile and compressive strength of the mortars, even when only a small percentage of salt is added.

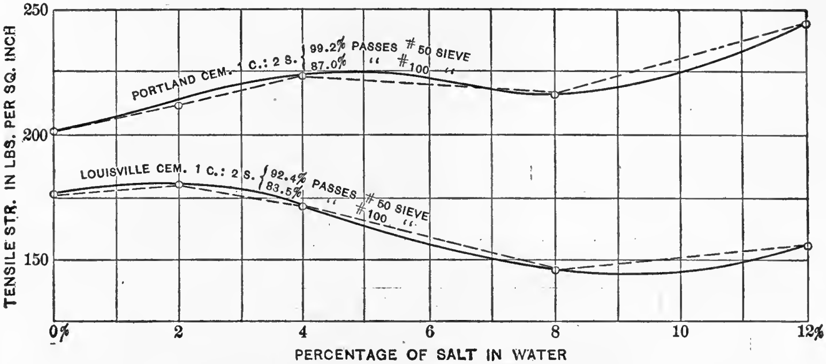

FIG. 53.*—Effect of salt on tensile strength.

The effect of salt on the strength of natural-cement mortars is shown in Figs. 51, 52, and 53. Of these Tetmajer's experiments were made on European natural-cement mortars, mixed 1 cement to 3 sand and tested at various ages. Those shown in Fig. 52 were made on Louisville and Portland-cement mortars and all tested at six months.

Tensile strength.—In tensile strength the average natural cement ranks considerably lower than the average Portland. This is particularly noticeable when the cements are tested with sand.

This general rule as to the relative strength of natural and Portland cements is well known, but the exceptions to the rule are not frequently discussed. It is a fact, however, that certain brands of natural cements are about as strong, either neat or with sand, as the average imported Portland, and there is no reason why a number of natural cements could not be carried up to this grade. The average results of extensive series of tests on various natural cements are given diagrammatically in Figs. 54, 55, 56, 57, 58, 59, and 60.

In Fig. 55 are shown the results of a very large number of tensile

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* From Johnson's "Materials of Construction", p. 618.

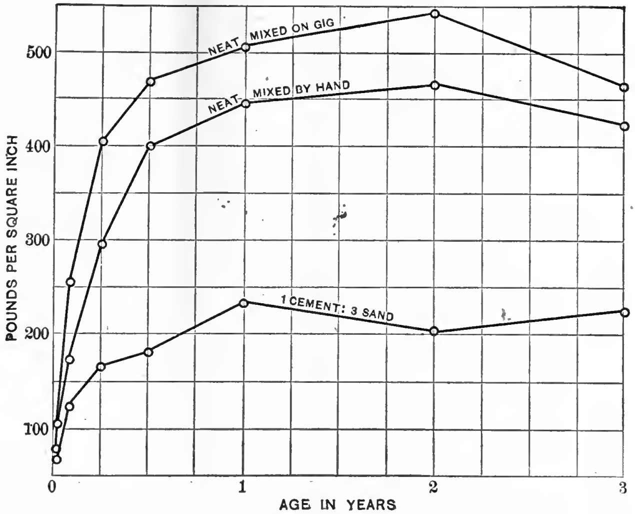

Fig. 54.*—Tensile strength of Louisville cement, St. Louis Waterworks, 1896.

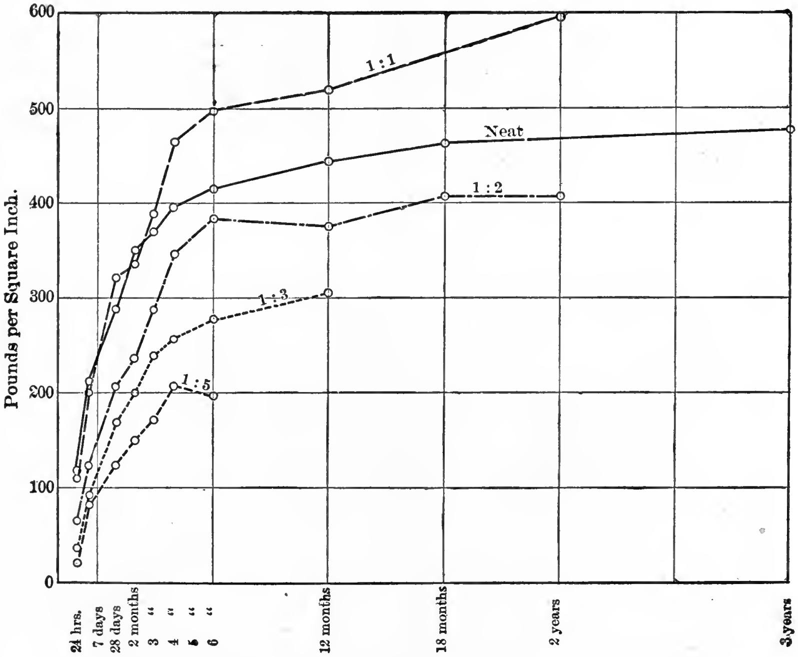

Fig. 55.—Tensile strength of Lehigh district natural cements. (Philadelphia tests, 1893, 1894, 1895, 1896.)

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* From Johnson's "Materials of Construction", p. 570.

tests, at various ages up to 3 years, on the "improved" natural cements of the Lehigh district of Pennsylvania.

The results of a number of tests of natural cements from the Cumberland-Hancock district of Maryland have been averaged and are shown diagramatically in Fig. 56.

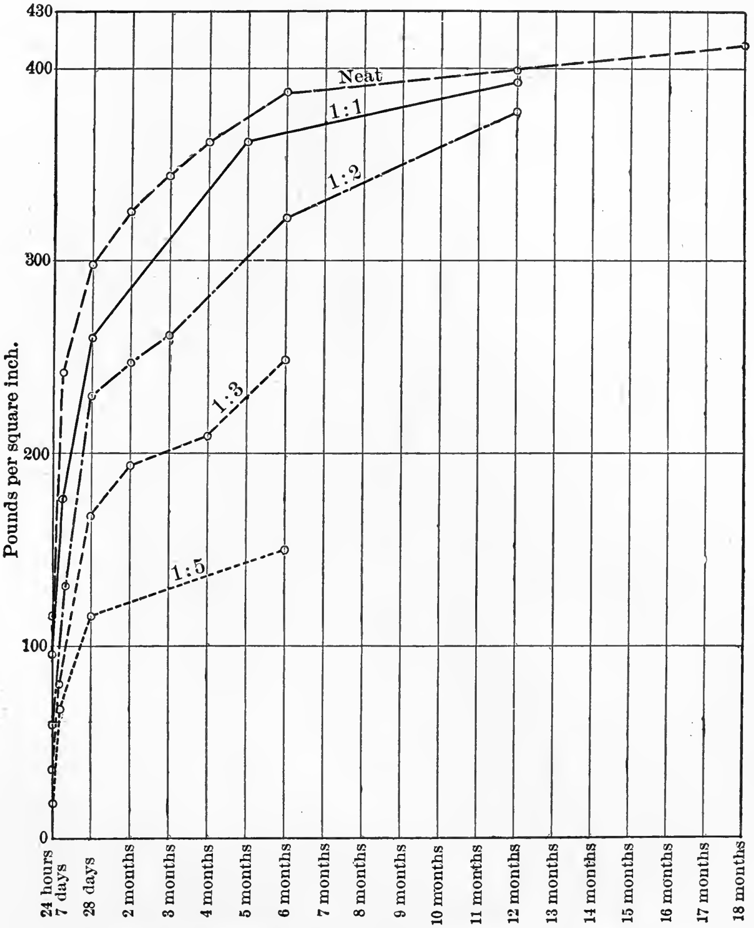

FIG. 56.—Tensile strength of Cumberland natural cements. (Philadelphia tests, 1894, 1895, 1896.)

Tests of natural cements from Akron, N. Y., and Cumberland, Md., during 1897 and 1898, are shown diagrammatically in Fig. 57. These tests cover ages of 1 day to 6 months.

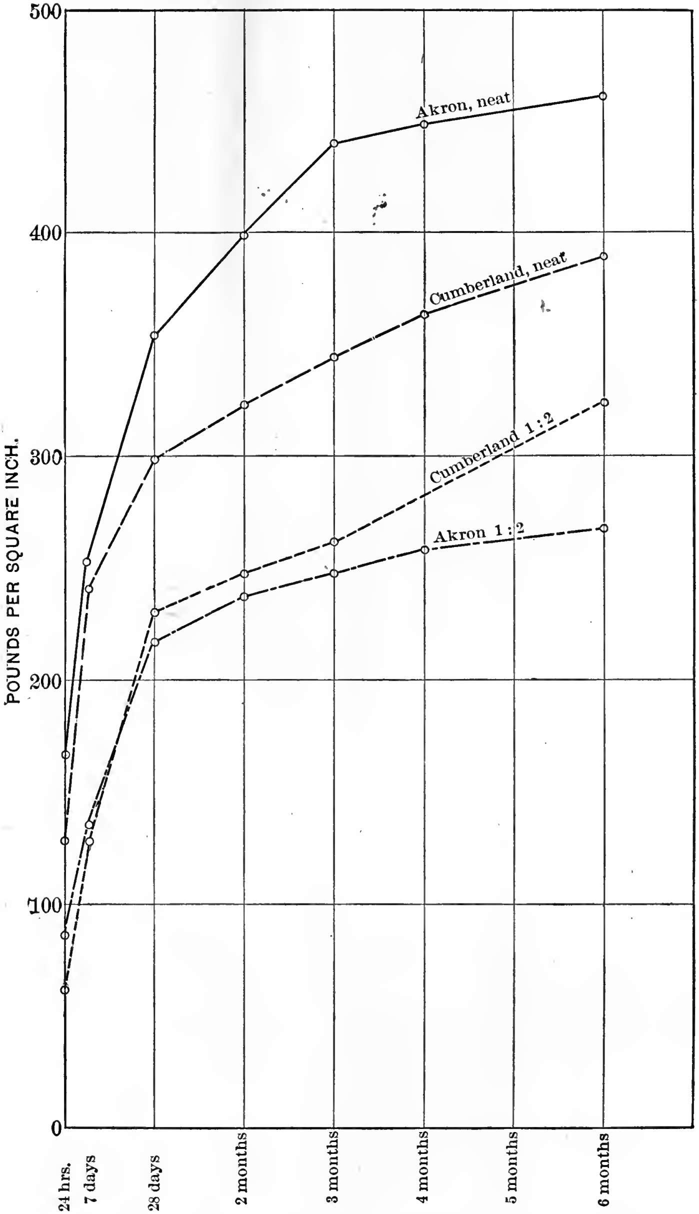

FIG. 57.—Tensile strength of Akron and Cumberland cements. (Philadelphia tests, 1897, 1898.)

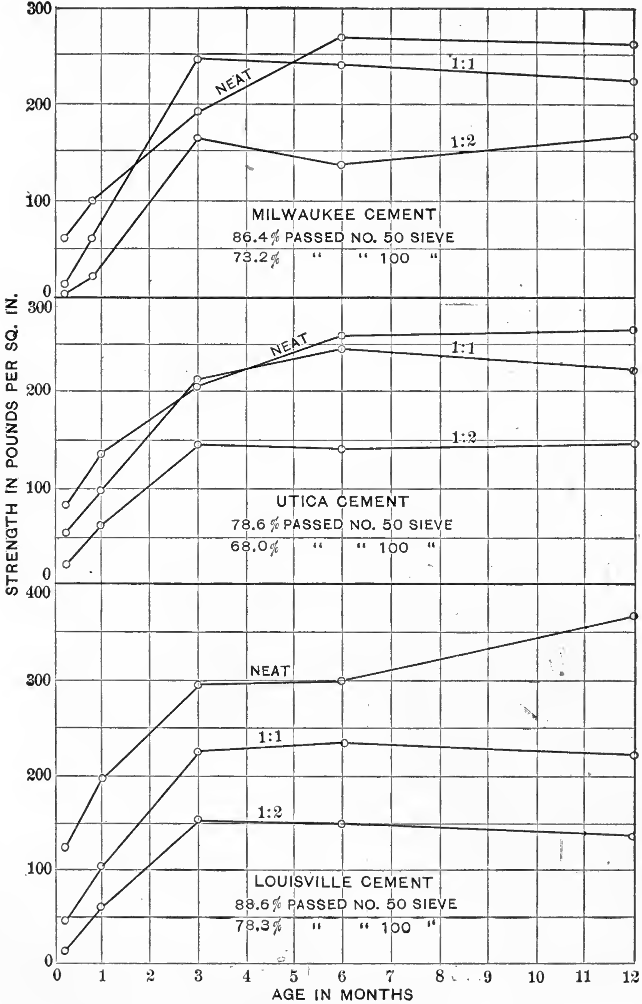

FIG. 58.*—Tensile strength of natural cements, Cairo Bridge tests.

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* From Johnson's "Materials of Construction", p. 569.

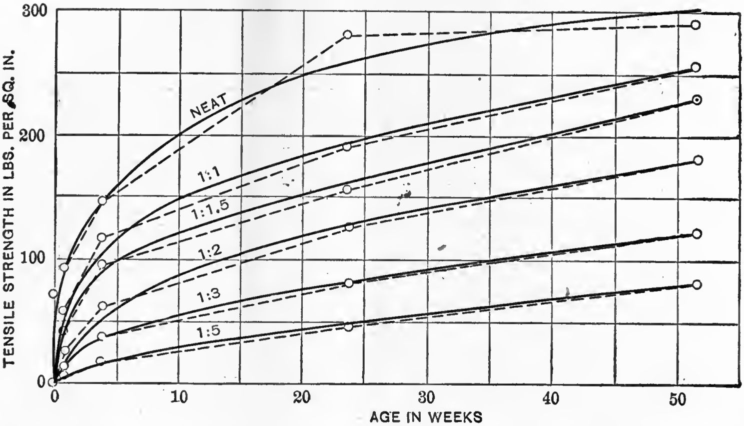

Fig. 59.*—Tensile strength Rosendale cements, Boston Main Drainage, 1885.

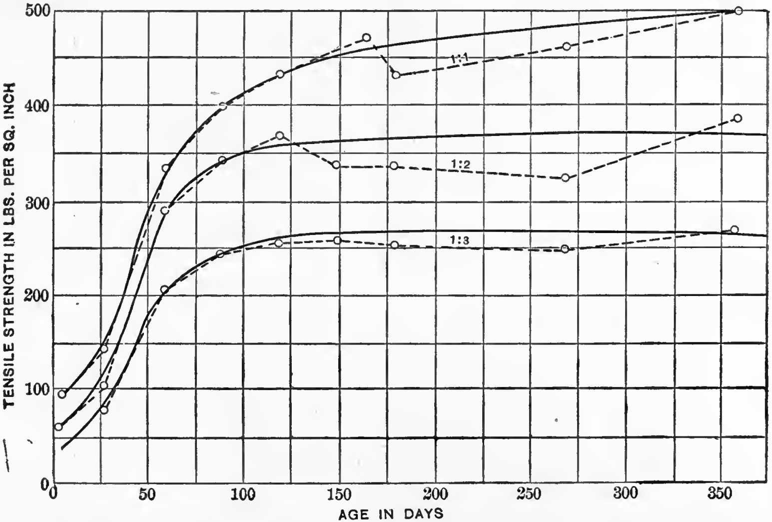

Fig. 60.†—Tensile strength natural cements, Sault Ste. Marie, 1894.

The effect on the tensile strength of varying the proportion of sand is well shown in the tests made by Sabin ‡ and summarized in Table 130. These tests are shown diagrammatically in Fig. 61.

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* From Johnson's "Materials of Construction", p. 568.

† Ibid., p. 570.

‡ Report Chief of Engineers, U. S. A., 1895, p. 2982.

TABLE 130.

EFFECT OF SAND ON TENSILE STRENGTH OF NATURAL CEMENT. (SABIN.)

Composition.		Tensile Strength.		
Cement.	Sand.	Maximum.	Minimum.	Average.
1	0	428	340	380
1	1	332	251	297
1	2	298	224	260
1	3	208	144	183
1	4	154	74	128
1	5	109	61	81
1	6	81	56	69
1	7	68	32	56
1	8	66	29	53

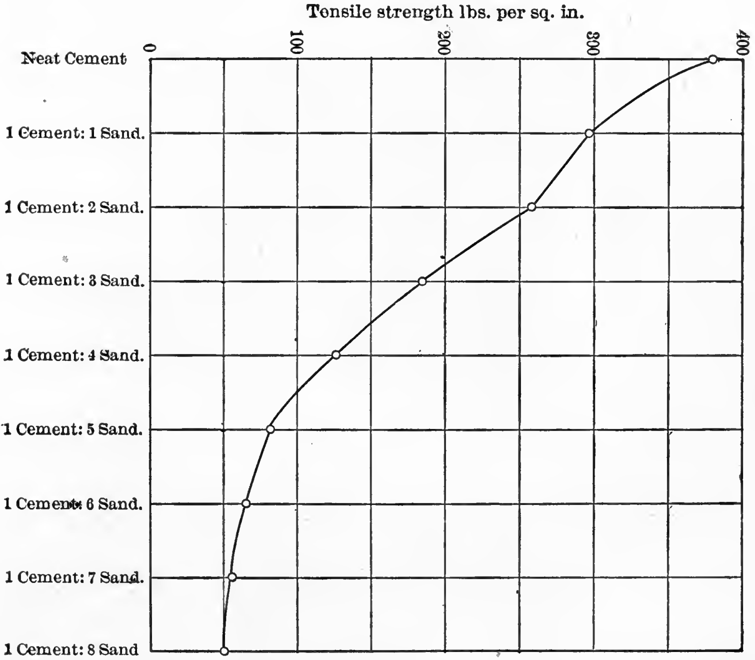

FIG. 61.—Effect of sand on tensile strength of natural cement. (Sabin.)

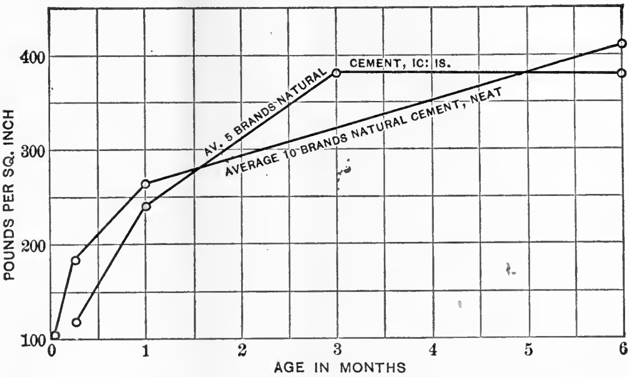

FIG. 62.*—Tensile tests, Sault Ste. Marie.

Compressive strength.—Tests on various natural cements carried out by Clifford Richardson † are summarized in Table 131.

TABLE 131.

COMPRESSIVE TESTS OF NATURAL CEMENTS. (RICHARDSON.)

	Neat Cement.			1 Cement, 2 Sand.		
	7 Days.	28 Days.	3 Months.	7 Days.	28 Days.	3 Months.
Buffalo, N. Y.	997	1300	....	700	980	
Akron Star, N. Y.	1325	2812	....	700	1300	
Louisville, Ky.	1737	2795	....	500	1065	
Milwaukee, Wis.	913	1457	....	506	822	
Fort Scott, Kan.	769	1256	....	417	680	
" " "	1072	2402	3155	988	1470	2718
Mankato, Minn.	1663	2288	....	575	834	
Utica, Ill.	1538	1972	....	1075	1450	
Rosendale, N. Y.	....	1737	....	....	614	
Average	1252	2002	3155	683	1024	2718

The following tests (Table 132) of compressive strength were made on 4-inch cubes at the Watertown Arsenal.‡

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* From Johnson's "Materials of Construction", p. 571.

† Brickbuilder, vol. 6, p. 253.

‡ Report on tests of metals, etc., at Watertown Arsenal for 1902, pp. 377–381.

TABLE 132.

COMPRESSIVE STRENGTH OF 4-INCH NATURAL-CEMENT CUBES. (WATERTOWN ARSENAL.)

Brand.	Per Cent Water.	Compressive Strength, Lbs. per Square Inch. 7 Days.	1 Month.	3 Months.	12 Months.
Austin, Minn	35.4	356	1090	1530	
Mankato, Minn.	41.2	566	1020	1420	
Potomac, Md.	39.2	423	840	1110	1100
Obelisk, Erie County, N. Y.	35.8	750	1360	2220	
Norton, Ulster County, N. Y.	39.6	472	880	1570	
Newark and Rosendale, Ulster County, N. Y.	38.7	407	1090	1440	1590
Hoffman.	36.2	464	790	1230	
Bonneville improved, Penna.	38.7	620	1130	1560	

TABLE 133.

EFFECT OF HEATING ON COMPRESSIVE STRENGTH. (WATERTOWN ARSENAL.)

Brand.	Mixture.	Per Cent Water.	Age. Yrs.	Mon.	Days	Heated to	Compressive Strength, Lbs. per Sq. In.
Mankato.	Neat cement	38	1	2	19	Not heated	1867
"	" "	38	1	2	19	200° F.	1657
"	" "	38	1	2	19	300° F.	1877
"	" "	38	1	2	19	400° F.	1967
"	" "	48	1	2	19	500° F.	1603
"	" "	48	1	2	19	600° F.	1453
"	" "	48	1	2	19	700° F.	1497
"	" "	48	1	2	19	800° F.	1400
"	" "	48	1	2	19	900° F.	1185
"	1 cement, 1 sand	28	1	6	21	Not heated	538
"	1 " 1 "	31	1	6	21	200° F.	491
"	1 " 1 "	31	1	6	21	300° F.	433
"	1 " 1 "	28	1	6	21	500° F.	471
"	1 " 1 "	28	1	6	21	700° F.	381
"	1 " 1 "	31	1	6	21	900° F.	317
"	1 " 1 "	31	1	6	21	500° F.	329

Ratio of compressive to tensile strength.—The ratio between the compressive and tensile strength is apparently, in the natural cements, considerably lower than in Portland cement.

TABLE 134.

RELATION OF TENSILE TO COMPRESSIVE STRENGTH OF NATURAL CEMENT. (SABIN.)

Brand.	Composition.	Age.	Average Tensile Strength, Pounds per Square Inch.	Average Compressive Strength, Pounds per Square Inch.	Ratio Compressive ÷ Tensile.
A..........	1 cement, 2 sand	28 days	116	662	5.71
B..........	1 " 2 "	28 "	187	1020	5.45
C..........	1 " 2 "	28 "	237	1175	4.96
D..........	1 " 2 "	28 "	117	550	4.70
E..........	1 " 2 "	28 "	286	1224	4.28
A..........	1 " 2 "	3 months	334	1261	3.77
B..........	1 " 2 "	3 "	294	1118	3.80
C..........	1 " 2 "	3 "	370	1698	4.59
D..........	1 " 2 "	3 "	298	1076	3.61
E..........	1 " 2 "	3 "	291	1018	3.50

Report Chief of Engineers, U. S. A., 1896, p. 2872.

The following tests were made by Prof. Creighton on samples of the Utica (Ill.) natural cement used in the construction of the drainage works at New Orleans.

TABLE 135.

RELATION OF TENSILE TO COMPRESSIVE STRENGTH OF UTICA NATURAL CEMENT. (CREIGHTON.)

Composition.	Age.	Average Tensile, Pounds per Square Inch.	Average Compressive, Pounds per Square Inch.	Ratio Compressive ÷ Tensile.
Neat cement..........	7 days	210		
" "	14 "	255	1300	5.09
" "	28 "	270	1705	6.32
" "	2 months	283		
" "	3 "	300		
" "	6 "	340	1805	5.31
1 cement, 1 sand......	7 days	136		
1 " 1 "	14 "	269	1170	4.35
1 " 1 "	28 "	290	1417	4.88
1 " 1 "	2 months	302	1583	5.24
1 " 1 "	3 "	....	1723	
1 " 1 "	6 "	313	1940	6.19
1 " 2 "	7 days	76		
1 " 2 "	14 "	114	568	4.98
1 " 2 "	28 "	162	655	4.05
1 " 2 "	2 months	164	840	5.12
1 " 2 "	3 "	172	1135	6.60
1 " 2 "	6 "	176	1768	10.05
1 " 3 "	7 days			
1 " 3 "	14 "	98	352	3.59
1 " 3 "	28 "	112	403	3.59
1 " 3 "	2 months	124		
1 " 3 "	3 "	131	456	3.48
1 " 3 "	6 "	138	923	6.68

Modulus of elasticity.—Tests of the modulus of elasticity of several American natural cements made at Watertown Arsenal* are summarized in Table 136.

TABLE 136.

MODULUS OF ELASTICITY.

Brand.	Composition.	Weight per Cu. Ft.	Age. Mo.	Da.	Ultimate Strength, Pounds per Sq. In.	*E.*
						Lbs. sq. in.
Austin.	Neat	100.6	2	14	610	E(100–500) = 567,000
Newark & Rosendale.	"	99.5	2	15	700	E(100–500) = 485,000
" " "	"	120	1		. . . .	E(100–500) = 988,000
" " "	"	120	5		2720	E(100–1000) = 1,818,000 E(1000–2000) = 1,342,000
Obelisk.	"	107.0	2	8	1430	E(100–500) = 976,000 E(500–1000) = 826,000
"	"	116.6	2	7	1900	E(100–1000) = 1,132,000
"	1 cement 1 sand	121.9	2	5	1330	E(100–1000) = 1,146,000

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* Report of tests of metals, etc., made at Watertown Arsenal, for 1902, pp. 501–505.

CHAPTER XX.

SPECIFICATIONS FOR NATURAL CEMENTS.

SEVERAL sets of specifications for natural cements are reprinted below, with a final comparative summary of their requirements on different points.

New York State Canals, 1896.

Natural hydraulic cement must be of the best quality and of such fineness that 90 per cent will pass through a sieve of 2500 meshes per square inch and 80 per cent through a sieve of 10,000 meshes per square inch.

Briquettes made of equal parts of natural hydraulic cement and crushed quartz, immersed in water as soon as they are sufficiently hard to sustain a $\frac{1}{24}$-inch wire weighted with 1 lb., must show a tensile strength of 65 lbs. per square inch at the expiration of seven days, but briquettes showing less than such strength will be held until twenty-eight days have elapsed, when, if they then show such strength as to sustain as many pounds per square inch above 125 as the seven-day test shows them to have fallen below 65 they will be deemed to have passed this test. Briquettes made of neat cement must not set so as to support a $\frac{1}{12}$-inch wire with a load of one quarter of a pound in less than five minutes. Briquettes of neat cement must not show checks or cracks when immersed in water for seven days after mixing.

Rapid Transit Subway, New York City, 1900–1901.

Fineness.—95 per cent shall pass a No. 50 sieve and 85 per cent a No. 100 sieve.

Tensile strength.—At the end of seven days, one day in air, six days in water, 125 lbs., neat. At the end of twenty-eight days, one day in air, twenty-seven days in water, 200 lbs., neat. When mixed 1 to 1 with quartz sand: at the end of seven days, one day in air, six days in water, 100 lbs.; at the end of twenty-eight days, one day in air, twenty-seven days in water, 150 lbs.

Soundness.—Tests for checking and cracking and for color will be made by molding, on plates of glass, cakes of neat cement about 3 inches in diameter, ½ inch thick in the center, and with very thin edges. One of these cakes when set perfectly hard shall be put in water and examined for distortion or cracks, and one shall be kept in air and examined for color, distortion, and cracks.

Engineer Corps, U. S. Army, 1901

(1) The cement shall be a freshly packed natural or Rosendale, dry, and free from lumps. By natural cement is meant one made by calcining natural rock at a heat below incipient fusion and grinding the product to powder.

(2) The cement shall be put up in strong, sound barrels, well lined with paper so as to be reasonably protected against moisture, or in stout cloth or canvas sacks. Each package shall be plainly labeled with the name of the brand and of the manufacturer. Any package broken or containing damaged cement may be rejected, or accepted as a fractional package, at the option of the United States agent in local charge.

(3) Bidders will state the brand of the cement which they propose to furnish. The right is reserved to reject a tender for any brand which has not given satisfaction in use under climatic or other conditions of exposure of at least equal severity to those of the work proposed.

(4) Tenders will be received only from manufacturers or their authorized agents.

(The following paragraph will be substituted for paragraphs 3 and 4 above when cement is to be furnished and placed by the contractor:

No cement will be allowed to be used except established brands of high-grade natural cement which have been in successful use under similar climatic conditions to those of the proposed work.)

(5) The average net weight per barrel shall not be less than 300 lbs. (west of the Allegheny Mountains this may be 265 lbs.) . . . sacks of cement shall have the same weight as 1 barrel. If the average net weight, as determined by test weighings, is found to be below 300 lbs. (265 lbs.) per barrel, the cement may be rejected, or, at the option of the engineer officer in charge, the contractor may be required to supply free of cost to the United States an additional amount of cement equal to the shortage.

(6) Tests may be made of the fineness, time of setting, and tensile strength of the cement.

(7) **Fineness.**—At least 80 per cent of the cement must pass through a sieve made of No. 40 wire, Stubb's gauge, having 10,000 openings per square inch.

(8) **Time of Setting.**—The cement shall not acquire its initial set in less than twenty minutes and must have acquired its final set in four hours.

(9) The time of setting is to be determined from a pat of neat cement mixed for five minutes with 30 per cent of water by weight and kept under a wet cloth until finally set. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire $\frac{1}{12}$ inch in diameter loaded to weigh $\frac{1}{4}$ lb. The final set has been acquired when the pat will bear, without being appreciably indented, a wire $\frac{1}{24}$ inch in diameter loaded to weigh 1 lb.

(10) **Tensile strength.**—Briquettes made of neat cement shall develop the following tensile strengths per square inch, after having been kept in air for twenty-four hours under a wet cloth and the balance of the time in water:

At the end of seven days, 90 lbs.; at the end of twenty-eight days, 200 lbs.

Briquettes made of one part cement and one part standard sand by weight shall develop the following tensile strengths per square inch:

After seven days, 60 lbs.; after twenty-eight days, 150 lbs.

(11) The highest result from each set of briquettes made at any one time is to be considered the governing test. Any cement not showing an increase of strength in the twenty-eight-day tests over the seven-day tests will be rejected.

(12) The neat cement for briquettes shall be mixed with 30 per cent of water by weight, and the sand and cement with 17 per cent of water by weight. After being thoroughly mixed and worked for five minutes the cement or mortar is to be placed in the briquette mold in four equal layers, each of which is to be rammed and compressed by thirty blows of a soft brass or copper rammer three quarters of an inch in diameter (or seven tenths of an inch square with rounded corners), weighing 1 lb. It is to be allowed to drop on the mixture from a height of about half an inch. Upon the completion of the ramming the surplus cement shall be struck off and the last layer smoothed with a trowel held nearly horizontal and drawn back with sufficient pressure to make its edge follow the surface of the mold.

(13) The above are to be considered the minimum requirements. Unless a cement has been recently used on work under this office, bid-

ders will deliver a sample barrel for test before the opening of the bids. Any cement showing by sample higher tests than those given must maintain the average so shown in subsequent deliveries.

(14) A cement may be rejected which fails to meet any of the above requirements. An agent of the contractor may be present at the making of the tests, or, in case of the failure of any of them, they may be repeated in his presence. If the contractor so desires, the engineer officer may, if he deems it to the interest of the United States, have any or all of the tests made or repeated at some recognized standard testing laboratory in the manner above specified. All expenses of such tests shall be paid by the contractor, and all such tests shall be made on samples furnished by the engineer officer from cement actually delivered to him.

American Society for Testing Materials. 1904.

11. **Definition.**—This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic-acid gas.

12. **Specific gravity.**—The specific gravity of the cement thoroughly dried at 100° C. shall be not less than 2.8.

13. **Fineness.**—It shall leave by weight a residue of not more than 10 per cent on the No. 100 and 30 per cent on the No. 200 sieve.

14. **Time of setting.**—It shall develop initial set in not less than ten minutes, and hard set in not less than thirty minutes, nor more than three hours.

15. **Tensile strength.**—The minimum requirements for tensile strength for briquettes 1 inch square in cross-section shall be within the following limits, and shall show no retrogression in strength within the periods specified.

NEAT CEMENT.

Age.	Strength.
24 hours in moist air	50–100 lbs.
7 days (1 day in moist air, 6 days in water)	100–200 "
28 days (1 day in moist air, 27 days in water)	200–300 "

1 PART CEMENT, 3 PARTS STANDARD SAND.

7 days (1 day in moist air, 6 days in water)	25– 75 "
28 days (1 day in moist air, 27 days in water)	75–150 "

16. **Constancy of volume.**—Pats of neat cement about 3 inches in diameter, ½ inch thick at center, tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(*a*) A pat is then kept in air at normal temperature.

(*b*) Another is kept in water maintained as near 70° F. as practicable.

17. These pats are observed at intervals for at least twenty-eight days, and, to satisfactorily pass the tests, should remain firm and hard and show no signs of distortion, checking, cracking, or disintegrating.

Comparison and Summary.

It is of interest to compare the requirements, on various points, of the specifications above printed. They differ considerably, as can be readily seen, in regard to fineness, strength, setting time, etc., etc.

Definition.—Of the four specifications above printed, two give no definition whatever and the others are very defective. The definition given by the American Society for Testing Materials would, for example, exclude almost every good natural cement in the country; for it is only the very low-limed cements that are burned "at a temperature only sufficient to drive off the carbonic-acid gas".

Specific gravity.—Only one specification contains any requirement in regard to specific gravity, and this places the minimum at 2.8. So far as is known to the writer, not even the worst possible natural cement, if burned at all, could fall much below this point.

Fineness.—The differences in the fineness requirements of the specification printed above, as well as of several other important specifications, are summarized in Table 137, below. The requirements of the American Society for Testing Materials (90 per cent through 100-mesh, 70 per cent through 200-mesh) are high, and probably cannot be economically attained unless modern grinding machinery is in use at the mill. With tube mills, however, this fineness can be readily reached, and the tensile strength of the cement is greatly improved.

Table 137.

Fineness Required by Various Specifications.

Specification.	Per Cent Required to Pass		
	50-mesh.	100-mesh.	200-mesh.
Engineer Corps, U. S. A., 1901	..	80	
New York State Canals, 1896	90	80	
Rapid-transit Subway, New York City, 1900–1901	95	85	
Philadelphia Department Public Works, 1893	96		
" " " " 1894–1895	99	85	60
" " " " 1896–1897	99	90	70
American Society for Testing Materials, 1904	..	90	70

Strength.—The tensile strength required is also highly variable in different specifications. These variations are shown in the summary below.

TABLE 138.

STRENGTH REQUIRED BY VARIOUS SPECIFICATIONS.

	Neat.			1:1.	
	1 Day.	7 Days.	28 Days.	7 Days.	28 Days.
N. Y. State Canals....	....	.....	.....	65 lbs.	125 lbs.
N. Y. Subway........	....	125 lbs.	200 lbs.	100 "	150 "
Engineer Corps, U.S.A.	....	90 "	200 "	60 "	150 "
Soc. Testing Materials.	50–100 lbs.	100–200 "	200–300 "	25–75* "	75–150* "

* In this specification the mortar mixture is 1 cement, 3 sand.

Product actually delivered.—Specification requirements are made for the purpose of preventing the use of poor material. They must therefore be set low enough to include all the good cement. For this reason the cement supplied to any important work is usually found, when tested, to be considerably better in every way than is required by the specifications. This fact is well brought out by the following tables, which give the experience of two important pieces of work.

TABLE 139.

CEMENT SUPPLIED TO NEW YORK RAPID-TRANSIT SUBWAY, 1900–1901.

	1900.	1901.
Barrels received............	5000	10,920
Neat cement:		
Briquettes broken........	411	750
" passed.........	363	750
" failed.........	48	0
7 days, specified.........	125 lbs.	125 lbs.
7 " average test.	172 "	215 "
28 days, specified........	200 "	200 "
28 " average test.	249 "	322 "
1 cement, 1 sand:		
Briquettes broken........	138	882
" passed.........	134	882
" failed.........	4	0
7 days, specified.........	100 lbs.	100 lbs.
7 " average test.	118 "	218 "
28 " specified........	150 "	150 "
28 " average test.	215 "	350 "

TABLE 140.

SUMMARY OF NATURAL-CEMENT TESTS, 1897–1900 (N. Y. STATE ENGINEER).

Locality.	Number of Tests.	Fineness. Per Cent Passing		Set.		Tensile Strength, 1 Cement, 1 Sand.	
		50-mesh.	100-mesh	Initial.	Final.	7 Days.	28 Days.
Ulster Co., N. Y.	215	95.0	88.2	33	56	81	196
Schoharie Co., N. Y....	12	92.2	84.6	23	41	113	226
Onondaga Co., N. Y.. .	3	91.8	80.5	27	40	122	263
Erie Co., N. Y.	54	93.6	85.5	18	31	104	216
Lehigh district, Pa.	1	92.0	81.8	30	45	61	131
Specified requirements.	...	90.0	80.0	5	..	65	125

CHAPTER XXI.

HISTORY, STATISTICS, AND PROSPECTS OF THE NATURAL-CEMENT INDUSTRY.

History of the Industry.

Natural cements were first made in England and France about 1800, and for a time the industry developed quite rapidly. In the United States the first manufacture was in 1819, the discovery of the raw material being due directly to the construction of the Erie Canal.

When the construction of the Erie Canal was first undertaken, the use of ordinary lime as a mortar material was contemplated. As a large amount of lime would be used for this purpose, many limestone-beds throughout the State were examined and tested. Good limes were found to be available at many points along the course of the canal, and the engineers had apparently no expectation of finding a better material. During the progress of work on the middle section of the canal, however, it was found that the lime burned from a certain stone refused to slake. The quarry from which this stone came had been opened on the land of T. Clarke, in the town of Sullivan, Madison County, in a bed of limestone which to all appearances was satisfactory enough.

The failure on the part of the contractor to deliver the lime brought the matter to the attention of Benjamin Wright, engineer in charge of the middle division, and Canvass White, one of his two associates. Fortunately, Mr. White had visited England in order to secure as much information as possible concerning the materials and methods then employed in the execution of great public works, and in the course of this visit he had devoted considerable time to a study of the various limes and cements used as mortar materials. Parker's "Roman cement" had then passed the experimental stage, and in both England and France natural cement was gradually but steadily supplanting lime as an engineering material The cost of Parker's cement, however, was an obstacle to its extensive use.

Because of this preliminary acquaintance with the subject, Mr. White was peculiarly well fitted to cope with the difficulty which had presented itself in Madison County. He visited the Clarke quarry, examined and tested both the quarry stone and the burned product, and decided that the obstinate lime was really a high-grade natural cement, which required only grinding to make it fit for use. Tests on a larger scale soon proved that his conclusion was correct, and the first American natural cement was put to extensive use in the locks and walls of the middle section of the canal during the years 1818–1819.

Fortunately, we have a contemporary professional estimate of the value of this material. Wright, in a letter dated in 1820, summarizes the facts regarding White's cement, stating that it "is found to be a superior water cement, and is used very successfully in the stonework of the Erie Canal, and believed to be equal to any of the kind found in any other country. It is pulverized (as it will not slack) and then used by mixing two parts lime and one part sand. It hardens best under water, and it is believed its properties are partially lost if permitted to dry suddenly, or if not used soon after mixing."

Eighty years of testing devices have hardly given us a more satisfactory summary of the properties of natural cements than is contained in Wright's last sentence.

Another contemporary account (1821) states that "the price of this lime, pulverized and burnt and delivered at Utica, is 20 cents the bushel."

Mr. White took out a patent on this cement and for several years a controversy raged as to the tenability of this patent. This was finally settled, so far as the State of New York was concerned, by the action of the legislature. In 1825 the patent rights for the State of New York were purchased from Mr. White for the sum of $10,000 by the State and immediately thrown open to the free use of the citizens of New York

It is pleasant to know that the discovery and prompt utilization of this new material by White and Wright were rewarded with equal promptness by their professional advancement on the canal work.

The chemical character of this first American natural cement is established by an analysis made in 1822 by Seybert of a sample of the limestone used in its preparation. The analysis gave the following results:

Silica (SiO_2)	11.766
Alumina (Al_2O_3)	2.733
Iron oxide (Fe_2O_3)	1.500
Lime (CaO)	25.000
Magnesia (MgO)	17.833
Carbon dioxide (CO_2)	39.333
Moisture	1.500
	99.665

If this analysis be accepted as representative of the rock used, the resulting cement would have a Cementation Index of 0.74, and at the present day would be regarded as a hydraulic lime rather than as a natural cement.

The use of the Madison County cement on the canal stimulated search for other deposits of cement rock. In Wright's letter he states that this rock "is found in great abundance in the counties of Madison, Onondaga, and Cayuga". He thus outlined what has since been the natural-cement district of central New York. Later in the same letter Wright remarks: "I do not know that it is found in the counties west of Cayuga, but presume from the geological character of that country it may be found in all the country west to Niagara, and probably farther west." Within a few years this proved to be a fact, cement rock being discovered in Erie County, in the extreme western part of the State.

The first natural cement manufactured in Erie County was made in 1824 at Williamsville, the quarry, kiln, and mill being near the creek. In 1839 Jonathan Delano erected cement works at Falkirk, near Akron, in which he made about 2000 barrels of cement the first year. He furnished the cement for the feeder dam at Tonawanda Creek and for the Genesee Valley Canal. In 1843 the business passed into the hands of James Montgomery, who increased the output to 10,000 barrels a year. The business afterwards came into the possession of Enos Newman, a partner of Montgomery, and has been in his family ever since.

In 1854, H. Cummings & Son established a natural-cement plant at Akron, which was operated for several years. This plant was succeeded by another, managed by sons of the founder. The Akron plant was sold to the Akron Cement Company in 1871, and the Cummings brothers erected another plant about two miles west of Akron.

The first natural cement made within the present limits of Buffalo was manufactured in 1850 by Warren Granger. His plant was located near Scajaquada Creek, just below the Main Street bridge, in what is now Forest Lawn Cemetery. In 1874 Lewis J. Bennett commenced the manufacture of natural cement at Buffalo Plains, near Main Street. This establishment, which has been carried on continuously under the control of the Bennett family, is now incorporated as the Buffalo Cement Company.

In following out the history of the western New York cement industry from 1824 to the present time, we have necessarily passed by the inauguration of manufacture in the greatest of all the natural-cement districts—the Rosendale region of eastern New York. Third among the districts in point of age, it soon became first as a producer, and has ever since maintained a high standard in both the quality and quantity of its output.

The discovery of cement rock and the commencement of manufacture of natural cement in the Rosendale district took place apparently about 1825, though there is considerable uncertainty as to the exact date to be assigned.

TABLE 141.

DATES OF ESTABLISHMENT OF NATURAL-CEMENT INDUSTRIES IN VARIOUS STATES.

State.	Location.	Date.
California	Benicia	1860
Connecticut	Kensington	1826
Georgia	Howard	1851
"	Rossville	1901
Illinois	Utica	1838
Indiana-Kentucky	Louisville	1829
Kansas	Fort Scott	1868
Maryland	Round Top	1837
"	Cumberland	1836
"	Antietam	1888
Minnesota	Mankato	1883
"	Austin	1895
New Mexico	Springer	1899
New York	Akron, Erie County	1839
" "	Williamsville, Erie County	1824
" "	Buffalo, Erie County	1850
" "	Onondaga-Madison Counties	1818
" "	Rosendale district	1825
" "	Howe's Cave	1870
North Dakota	Pembina	1895
Ohio	Defiance	1846
"	Barnesville	1858
Pennsylvania	Williamsport	1831
"	Lebanon (?)	1825 (?)
"	Lehigh district	1850
Virginia	Balcony Falls	1848
West Virginia	Shepherdstown	1829
Wisconsin	Milwaukee	1875

The industry, however, had not secured so firm a foothold in the district by 1837 as might be expected, for in 1843 Mather, of the First Geological Survey of New York State, referred to the immediate past as follows: "When making the reconnaissance, soon after the commencement of the geolgical survey, the business had but commenced, and there was no cement manufactured on the Rondout except at Lawrenceville, and there but few kilns were in operation. It was not then known to the inhabitants that the cement rock was abundant except at and near these quarries until some of them were then informed of its inexhaustible quantities. Even now few are aware of the great extent of the rock and still fewer understand how to trace out the situation of favorably located new quarries."

During the six years that had elapsed since 1837, however, the industry seems to have grown rapidly, for in his final report (1843) Mather states that sixteen firms, working sixty kilns, were then operating in the Rosendale district. He estimated the product at 500,000 to 600,000 barrels per year, and notes that about 700 men were employed in the quarries, in the mills, and in handling the cement.

After the industry had become established in New York, it was taken up soon in several other States. It is a noteworthy fact, first pointed out by Mr. Lesley, that all these early plants were located along canals, and that in each case the natural-cement rock was discovered through search for a satisfactory mortar material for canal masonry.

Statistics of the American Industry.

Since within very wide limits of composition any clayey limestone will give a natural cement on burning, it can readily be seen that satisfactory natural-cement materials must be widely distributed and of common occurrence. Hardly a State is entirely without limestones sufficiently clayey to be available for natural-cement manufacture. The sudden rise of the American Portland-cement industry, however, has acted to prevent any great recent expansion of the natural-cement industry. It would be difficult to place a new natural cement on the market in the face of competition from both Portland cement and from the older and well-established brands of natural cement. Such new natural-cement plants as have been started within recent years have mostly been located in old natural-cement districts, where the accumulated reputation of the district would help to introduce the new brand. The only exceptions to this rule, indeed, were the Pembina plant in North Dakota, the Rossville plant in Georgia, and a plant in the State of Washington. Of these the Pembina plant was established with the intention of making Portland cement, but the raw materials soon proved to be unsuitable, and the plant was converted. The plant in Washington is located in an area where any kind of cement is readily salable. The Rossville plant was built by an Akron, N. Y., cement manufacturer, to utilize a peculiarly satisfactory natural-cement rock.

The following table taken from the annual volume on Mineral Resources, issued by the U. S. Geological Survey, shows the quantity and value of the natural cement produced in the United States in 1901, 1902, and 1903:

TABLE 142

PRODUCTION OF ROCK CEMENT IN 1901, 1902, AND 1903, BY STATES.

State.	1901.			1902.			1903.		
	Number of Works.	Quantity.	Value.	Number of Works.	Quantity.	Value.	Number of Works.	Quantity.	Value.
		Barrels.			Barrels.			Barrels.	
Georgia	2	50,577	$40,967	2	55,535	$31,444	2	80,620	$44,402
Illinois	2	469,842	187,936	3	607,820	156,855	3	543,132	178,900
Indiana and Kentucky	15	2,150,000	752,500	15	1,727,146	869,163	15	1,533,573	766,786
Kansas	[1] 2	175,560	97,002	2	160,000	80,000	2	226,293	169,155
Maryland	4	351,329	175,665	4	409,200	150,680	4	269,957	138,619
Minnesota	[2] 2	126,000	63,000	2	150,000	67,500	2	175,000	78,750
Nebraska	1								
New York	[3] 18	2,234,131	1,117,066	19	3,577,340	2,135,036	20	2,417,137	1,510,529
North Dakota	1	....	....	1	....	....	1		
Ohio	[4] 1	104,000	62,400	2	....	....	2	67,025	46,776
Pennsylvania	7	942,364	376,954	6	796,876	340,669	7	1,339,090	576,269
Texas	1	....	....	1	....	....	2		
Virginia	1	....	....	2	34,000	20,000	2	47,922	25,961
West Virginia	1	....	....	1	88,475	62,655	1		
Wisconsin	2	481,020	182,788	2	437,913	162,628	2	330,522	139,373
Total	[5] 60	7,084,823	3,056,278	[6] 62	8,044,305	4,076,630	[7] 65	7,030,271	3,675,520

---

[1] Includes product of Nebraska and Texas.

[2] Includes product of North Dakota.

[3] The number of companies producing natural cement only is given, and the number given for 1899 and 1900 has been changed accordingly, as in those years the *total* number of companies in the State was given.

[4] Includes product of Virginia and West Virginia.

[5] This total includes one plant in North Dakota, which for this year is reported as having a natural-cement product.

[6] The States combined for 1902 are noted in the text of the report for 1902.

[7] The States wherein the product of cement was combined with that of some other State for 1903 are given on page 291.

"The single cement plant in North Dakota has a production which for 1903 has been combined with that of the only plants producing natural cement in Kansas and Texas. The other States stand in the table exactly as the reported productions are given.

"The total results of combined productions are placed against those States which contributed the greater proportion of cement to make the entire quantity."

The following figures, also taken from the volume on Mineral Resources, issued annually by the U. S. Geological Survey, are of interest in this connection:

TABLE 143.

TOTAL PRODUCTION OF NATURAL-ROCK, PORTLAND, AND SLAG CEMENT IN THE UNITED STATES, 1818–1904.

Year.	Natural, Barrels.	Portland, Barrels.	Puzzolan or Slag, Barrels.
1818 to 1830	300,000		
1830 " 1840	1,000,000		
1840 " 1850	4,250,000		
1850 " 1860	11,000,000		
1860 " 1870	16,420,000		
1870 " 1880	22,000,000	82,000	
1880	2,030,000	42,000	
1881	2,440,000	60,000	
1882	3,165,000	85,000	
1883	4,190,000	90,000	
1884	4,000,000	100,000	
1885	4,100,000	150,000	
1886	4,186,152	150,000	
1887	6,692,744	250,000	
1888	6,253,295	250,000	
1889	6,531,876	300,000	
1890	7,082,204	335,000	
1891	7,451,535	454,813	
1892	8,211,181	547,440	
1893	7,411,815	590,652	
1894	7,563,488	798,757	
1895	7,741,077	990,324	
1896	7,970,450	1,543,023	12,265
1897	8,311,688	2,677,775	48,329
1898	8,418,924	3,692,284	150,895
1899	9,868,179	5,652,266	335,000
1900	8,383,519	8,482,020	446,609
1901	7,084,823	12,711,225	272,689
1902	8,044,305	17,230,644	478,555
1903	7,030,271	22,342,973	525,896
1904	4,866,331	26,505,881	303,045
Total	213,998,857	106,114,077	2,573,283

"The figures for natural-rock and Portland cement in this table through the year 1896 are taken from a statement made by Mr. Uriah

Cummings, of Akron, N. Y., in his volume entitled 'American Cements, 1898', on page 288." The remainder of the table is compiled from the United States Geological Survey reports on the production of cement.

In making a comparison it must of course be borne in mind that the barrel of Portland cement contains 380 lbs. net, while the natural-cement barrel varies from 240 lbs. to 300 lbs.

Prospects of the Industry.

Reference to the tables of statistics on preceding pages will show that the natural-cement production of the United States has been practically stationary since 1890. During this period, while the annual American production of Portland cement has advanced from 335,000 barrels to 22,342,973 barrels, the annual production of natural cement has varied between 7,030,271 and 9,868,179 barrels, the lowest prodution for any year being that of 1903. In view of these facts and of freely expressed prophecies that the natural-cement industry is gradually nearing its end, it seems desirable to sum up the prospects of the industry from the viewpoint of a disinterested outsider.

Engineers, both in text-books and in conversation, bring two charges against the natural cements as a class. Since the fate of the natural-cement industry will be decided finally by the verdict of the engineer who uses the product, it will pay to critically examine these charges. The faults alleged are: (1) lack of *strength* as compared with Portland cements, and (2) lack of *uniformity* in both composition and strength.

It may as well be admitted that both of these charges are true as regards the majority of natural cements as now made, but the writer cannot admit either that these faults are universal, or that they are unavoidable.

In regard to the first point an advocate of the natural cements could point out that three brands of natural cements are now regularly advertised and sold as Portland cements; that they have been tested for use in both State and Federal public works, including canals, locks, dams, and breakwaters; and that neither State nor army engineers seem to have even suspected that they are *not* Portland cements. This is surely a proof that *all* natural cements are not so low in strength as to be readily distinguished from Portlands by ordinary physical tests. So far as lack of uniformity is concerned, attention might be called to several American brands of natural cements whose variation in composition and strength is no more than is shown by the average brand of Portland cement. The faults charged against the natural cements are not, therefore, universal.

There remains to be considered the second point: whether, when these faults do occur, they are unavoidable and inherent in the idea of a natural cement, or whether, on the other hand, they can be avoided economically. To the present writer it seems obvious that most brands could, with sufficient care, be freed from both faults, and that this improvement could be carried out without raising the cost of manufacture to a profitless point.

In regard to chemical control of the raw material and product, it can be said that, with very few exceptions, none is attempted in the American natural-cement industry. The plants of the Lehigh district of Pennsylvania, which are run in connection with Portland-cement plants, are, of course, better off in this respect than the others. Excluding these Pennsylvania plants, there is, to the writer's knowledge, only one American natural-cement plant which employs a chemist. It seems only right that the name of this honorable exception should be published —it is the Pembina Cement Company, of North Dakota.

Careful analyses of the raw material and the product will, as pointed out earlier in this volume, enable the manager to select the proper burning-point for his rock, and to correct any defects in its composition. Few quarries show rock of such uniform character that it can all be burned at the same temperature, yet at most plants this is just what is attempted.

The product must also be given more careful treatment after burning, both in regard to seasoning and grinding. At the present day there is no reason why a coarsely ground or unsound natural cement should be put on the market. Economical fine-grinding machines are obtainable and should be installed. They will soon repay their first cost, and their high power consumption per unit is more than made up by the great increase in the amount and quality of the output.

PART VI. PORTLAND CEMENT.

CHAPTER XXII.

PORTLAND CEMENT: PRELIMINARY STATEMENTS.

In the chapters of the present section the raw materials, methods of manufacture, and properties of Portland cement will be taken up and discussed in turn. In order that the statements made in these chapters—and particularly in those on raw materials—may be clearly understood, it seems advisable to preface the section with a brief explanation regarding the definition, composition, and constitution of Portland cement. This brief explanation is accordingly given in the present chapter, while in Chapters XXIX and XXXVIII the subject of composition and constitution will be discussed in the greater detail warranted by their importance.

Origin of the name " Portland ".—In 1824 Joseph Aspdin took out a patent in England on the manufacture of a cement by calcining a mixture of limestone and clay. To the resulting product he gave the name "Portland", in allusion to a fancied (and in reality very slight) resemblance between the set cement and the famous oolitic limestone so extensively quarried for building purposes at Portland, England, and known to all English architects and engineers as "Portland stone".

"Portland" cement obtained its name, therefore, because it looked like Portland stone, and *not* because Portland was the place of its manufacture. On the contrary, it is not now, and never has been, manufactured at either Portland, Me., Portland, Ore., or Portland, England. This statement as to the origin of the name may seem unnecessary, but the writer has found many contractors or other users of Portland cement who believed that the only proper Portland must naturally be made at Portland—a belief which is fostered by the myriad of post-offices and villages bearing that name which have sprung up in the wake of the American cement industry.


129°
125°
121°
117°
113°
109°
105°
101°
45°
41°
37°
33°
29°
25°
C A N
WASHINGTON
Seattle
Tacoma
Olympia
Spokane
Portland
Salem
Columbia River
Snake River
Lewiston
OREGON
Ashland
Klamath R.
IDAHO
Salmon R.
Boise
Snake Riv.
Pocatello
MONTANA
Great Falls
Missouri River
Helena
Butte
Bozeman
Billings
Yellowstone Riv.
Bighorn R.
Powder R.
YELLOWSTONE NATIONAL PARK
Sheridan
WYOMING
Laramie
Cheyenne
NORTH DAKOTA
Bismarck
SOUTH DAKOTA
Pierre
Hot Springs
Sioux
NEBRASKA
Platte Riv.
CALIFORNIA
Sacramento Riv.
Sacramento
Oakland
San Francisco
Stockton
San Joaquin Riv.
Tulare Lake
Santa Barbara
Los Angeles
San Diego
NEVADA
Virginia
Carson
Eureka
UTAH
Great Salt Lake
Ogden
Salt Lake City
Provo
Nephi
Green R.
Grand R.
Colorado R.
COLORADO
Leadville
Denver
Pueblo
Durango
KANSAS
Arkansas R.
OKLAHOMA
Oklahoma
Cement
Quanah
ARIZONA
Prescott
Phoenix
Gila R.
Tucson
Colorado River
NEW MEXICO
Santa Fe
Albuquerque
Rio Grande
El Paso
TEXAS
Fort Worth
Colorado R.
Austin
San Antonio
Nueces R.
Rio Grande
MEXICO
LOWER CALIFORNIA
GULF OF CALIFORNIA
PACIFIC OCEAN
L.L.POATES ENGR., N.Y.
117°
113°
109°
105°
101°
100
0
100
200

MAP OF THE UNITED STATES

SHOWING LOCATION OF PORTLAND CEMENT PLANTS

FIG. 63.

[*To face p. 294.*

Recurring to Aspdin's work, it is to be noted that his original patent did not specify the percentages in which the two raw materials were to be mixed, and that it also omitted any mention of the high temperature necessary to secure a good product. The earliest Portland was probably, so far as its properties were concerned, like one of our poorer low-limed grades of natural cements. These defects were, however, overcome when Aspdin took up the manufacture on a commercial scale, and before 1850 the new product had established its value. In later chapters further details may be found concerning the early history and growth of the industry, both in Europe and in America.

Present use of the term "Portland".—While there is at present a fairly close general agreement as to what is to be understood by the term "Portland cement", a few points of importance are still open questions. Partly in consequence of this uncertainty, but more largely because of the intense imitativeness of specification-makers, the definitions of the term given in specifications and text-books are usually vague and unsatisfactory.

It is commonly agreed that the cement mixture must consist essentially of lime, silica, and alumina in proportions which can vary but slightly, and that this mixture must be burned at a temperature which will give a semi-fused product—a "clinker". These points must therefore be included in any satisfactory definition. The principal point regarding which there is a difference of opinion is whether or not cements made by burning a natural rock without previous mixing and grinding can under any circumstances be considered true Portlands. The question as to whether the definition of Portland cement should be drawn so as to include or exclude such products is evidently largely a matter of convention; but, unlike most conventional issues, the decision has very important practical consequences. The question at issue may be stated as follows:

If we make artificial mixture of the raw materials and a very high degree of burning the criteria on which to base our definition, we must in consequence of that decision exclude from the class of Portland cements certain well-known products manufactured at several points in France and Belgium by burning a natural rock without previous fine crushing or artificial mixture and at a considerably lower temperature than is attained in ordinary Portland-cement practice. These "natural Portlands" of France and Belgium have been considered Portland cements by some of the most critical authorities, though all agree that they are not particularly *high-grade* Portlands. So that a definition based upon the criteria above named will of necessity exclude from our class of Portland cements some meritorious products. But, on the other hand, such a restricted definition would have decided advantages.

There is no doubt that in theory a rock could occur containing lime, silica, and alumina in such uniformly correct proportions as to always give a good Portland cement on burning. Actually, however, such a perfect cement rock is of extremely rare occurrence. As above stated, certain brands of French and Belgian "Portland" cements are made from such natural rocks without the addition of any other material; but these brands are not particularly high grade, and in the better Belgian cements the composition is corrected by the addition of other material to the cement rock before burning.

The following definition of Portland cement is of importance because of the large amount of cement which will be accepted annually under the specifications * in which it occurs. It is also of interest as being the nearest approach to an official definition of the material that we have in this country:

"By a Portland cement is meant the product obtained from the heating or calcining up to incipient fusion of intimate mixtures, either natural or artificial, of argillaceous with calcareous substances, the calcined product to contain at least 1.7 times as much of lime, by weight, as of the materials which give the lime its hydraulic properties, and to be finely pulverized after said calcination, and thereafter additions or substitutions for the purpose only of regulating certain properties of technical importance to be allowable to not exceeding 2 per cent of the calcined product."

It will be noted that this definition does not require pulverizing or artificial mixing of the materials prior to burning. It seems probable that the Belgian "natural Portlands" were kept in mind when these requirements were omitted. In dealing with American-made cements, however, and the specifications in question are headed "Specifications for American Portland Cement", it is a serious error to omit these requirements. No true Portland cements are at present manufactured in America from natural mixtures without pulverizing and artificially mixing the materials prior to burning. Several natural-cement plants, however, have placed on the market so-called Portland cements made by grinding up together the underburned and overburned materials formed during the burning of natural cements. Several of these brands contain from 5 to 15 per cent of magnesia, but even if that fact be disregarded, there is no warrant or excuse for con-

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* Professional Paper No. 28, Corps of Engineers, U. S. A., p. 30.

sidering such products as true Portland cements. Nevertheless, there is absolutely nothing in the definition above quoted that would prevent their acceptance; and as a matter of fact at least one of these brands has been submitted, accepted, and used under these specifications.

The definition above discussed is fairly typical of those now to be found in American cement specifications.

The definition below has recently (1903–1904) been adopted by the Association of German Portland Cement Manufacturers:

Portland cement is a hydraulic cementing material with a specific gravity of not less than 3.10 in the calcined condition, and containing not less than 1.7 parts by weight of lime to each one part of silica + alumina + iron oxide, the material being prepared by intimately grinding the raw ingredients, calcining them to not less than clinkering temperature, and then reducing to proper fineness.

In view of the conditions above noted, the writer believes that the following definition will be found more satisfactory than those now in use for insertion as a preliminary requirement in cement specifications.

"**Definition of Portland cement.**—By the term Portland cement, as used in these specifications, is to be understood the product obtained by finely pulverizing clinker produced by burning to semi-fusion an intimate artificial mixture of finely ground calcareous and argillaceous materials, this mixture consisting approximately of three parts of lime carbonate (or an equivalent amount of lime oxide) to one part of silica, alumina, and iron oxide. The ratio of lime (CaO) in the finished cement to the silica, alumina, and iron oxide together shall not be less than 1.6 to 1, or more than 2.3 to 1."

The ratios of lime to silica, alumina, and iron oxide given in the last sentence of the above definition have been determined by examination of a large series of analyses of standard brands of American Portland cements, and it is very unlikely that any good Portland, as at present made, will have a ratio falling outside the limits above given. Occasionally, however, analyses will come very close to these limits, values of 1.64 and 2.29 respectively having been obtained from good brands. A value as low as 1.6 to 1.7 means a low-testing but absolutely safe cement. Values above 2.0 will include the high-testing brands.

Composition and constitution.—Portland cements may be said to tend toward a composition approximating to pure tricalcic silicate ($3CaO,SiO_2$) which would correspond to the proportion CaO 73.6 per cent, SiO_2 26.4 per cent. As can be seen, however, from the analyses quoted in Chapter XXXVIII actual Portland cements as at present made differ in composition very markedly from this. Alumina is always present in considerable quantity, forming with part of the lime the dicalcic aluminate ($2CaO, Al_2O_3$). This would give, as stated by Newberry, for the general formula of a pure Portland,

$$X(3CaO,SiO_2), \quad Y(2CaO,Al_2O_3).$$

But the composition is still further complicated by the presence of accidental impurities or intentionally added ingredients. These last may be simply adulterants, or they may be added to serve some useful purpose. Calcium sulphate is a type of the latter class. It serves to retard the set of the cement and in small quantities appears to have no injurious effect which would prohibit its use for this purpose. In dome kilns, sufficient sulphur trioxide is generally taken up by the cement from the fuel gases to obviate the necessity for the latter addition of calcium sulphate, but in the rotary kiln its addition to the ground cement, in the form of either powdered crude gypsum or plaster of Paris, is a necessity.

Iron oxide, within reasonable limits, seems to act as a substitute for alumina, and the two may be calculated together. Magnesium carbonate is rarely entirely absent from limestones or clays, and magnesia is, therefore, almost invariably present in the finished cement but in small percentage. Though magnesia, when magnesium carbonate is burned at low temperature, is an active hydraulic material (see Chapter XII) it does not normally combine with silica or alumina at the clinkering heat employed in Portland-cement manufacture. At the best it is an inert and valueless constituent in the normal Portland * cement; many regard it as positively detrimental in even small amounts, and because of this feeling manufacturers prefer to carry it as low as possible. In amounts of less than 3½ per cent to 5 per cent it is certainly harmless—and American Portlands from the Lehigh district usually reach well up toward that limit. In European practice it is carried somewhat lower.

Cementation Index.—In discussing the hydraulic limes and natural cements, use has been made of the Cementation Index, a device which affords an easy means of comparing the hydraulic and other properties of various cements. In dealing with Portland cement, this device

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* This statement should not be construed to mean that it is impossible to make a good cement of the Portland type, but containing high percentages of magnesia, for this very possibility will be discussed on a later page (p. 348). But such a magnesia Portland will, of necessity, differ quite markedly both in preparation and properties from the lime Portlands now in use.

reaches its maximum of efficiency and becomes of great service in every phase of the subject, from the selection of the raw materials and the proportioning of the mix to the valuation of the finished product. In later chapters the basis and determination of the Cementation Index will be found discussed in detail. In the present chapter it is only necessary to state that its value is obtained from the following formula:

$$\text{Cementation Index} = \frac{\begin{array}{l}(2.8\times\text{percentage silica})+\\(1.1\times\text{percentage alumina})+\\.7\times\text{percentage iron oxide}\end{array}}{\text{Percentage lime (CaO)}+1.4\text{ percentage magnesia}}.$$

This formula is applicable to raw materials as well as to cements, but the user must recollect that the first factor in the divisor is based on the percentage of lime (CaO), not of lime carbonate ($CaCO_3$), and similarly with the magnesia.

The Cementation Index, determined as above described, is a measure of the degree of basicity of a cement, or the relation of the acid (SiO_2,Al_2O_3,Fe_2O_3) to the basic (CaO,MgO) factors in its composition. A high cementation index means a high-limed and low-clayed cement, while a low index would mean the opposite. In Portland cements as at present made the Cementation Index will commonly fall within the limits of 1.00 and 1.20, 1.00 being the ideal index for a Portland.

Silica-alumina ratio.—The ratio between the silica and the alumina +iron oxide gives the second important index to the character of a cement. For convenience of reference this may be termed the silica-alumina ratio. This ratio, properly speaking, should take into account the different combining weights of the three compounds concerned, and would, therefore, theoretically be found from the formula

$$\text{Acidity Index} = \frac{2.8\times\text{percentage silica}}{(1.1\times\text{percentage alumina})+(.7\times\text{percentage iron oxide})}.$$

To the value determined by this formula the term "Acidity Index" might be very properly applied. But in ordinary practice the percentage of iron oxide present is so small that the ratio between the silica and the alumina+iron is given correctly enough by simple division, i.e.,

$$\frac{\text{Percentage silica}}{\text{Percentage alumina}+\text{percentage iron oxide}}.$$

The value thus obtained will be called briefly the silica-alumina ratio (though it considers the iron oxide also). It may be said that the percentage of lime being constant, the clinkering temperature decreases with the silica-alumina ratio; while the setting-time and ultimate strength of the cement are in inverse proportion to the values of the ratio.

Kinds of material used.—Before taking up the detailed discussion of the various raw materials used in the manufacture of Portland cement, some general statements on the kinds and combinations of raw materials actually in use will probably be found serviceable.

In order that the value and availability of different raw materials may be estimated, it will be convenient to assume a certain ideal composition for a cement rock. For the purposes of the present chapter this can be done in a sufficiently accurate way by considering that a Portland-cement mixture, when ready for burning, should contain about 75 per cent of lime carbonate ($CaCO_3$), and about 20 per cent of silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) together, the remaining 5 per cent or so containing any magnesia, sulphur, and alkalies that may be present. More exact information on these points will be found in Chapter XXIX, where a somewhat detailed discussion of the calculation and composition of Portland-cement mixtures, together with a number of analyses of actual mixtures and cements, will be given.

The essential elements which enter into this mixture—lime, silica, alumina, and iron—are all abundantly and widely distributed in nature, occurring in different forms in many kinds of rocks; and it can readily be seen that, theoretically, a satisfactory Portland-cement mixture could be prepared by combining, in an almost infinite number of ways and proportions, many possible raw materials. Obviously, too, we might expect to find perfect gradations in the degree of *artificialness* of such a mixture, varying from the one extreme where a natural rock of almost absolutely correct composition was used to the other extreme where two or more materials in nearly equal amounts were required to produce a mixture of correct composition.

The almost infinite number of raw materials which are theoretically available are, however, reduced to a very few in practice under existing commercial conditions. The necessity for producing the mixture as cheaply as possible rules out of consideration a large number of materials which would be considered available if chemical composition was the only thing to be taken into account. Some materials otherwise suitable are too scarce and consequently too expensive for such use; some are too difficult to pulverize finely and bring into combination. In consequence comparatively few combinations of raw materials are actually in use.

In certain favored localities deposits of argillaceous (clayey) limestones or "cement rock" have been found in which the lime, silica, alumina, and iron oxide exist in so nearly the proper proportions that only a relatively small amount (say 10 per cent or so) of other material, added before calcination, is required in order to make a mixture of correct composition. Certain blast-furnace slags are also close in composition to the desired mixture, and are used like "cement rock".

In the majority of plants, however, most or all of the necessary lime is furnished by one raw material, while the silica, alumina, and iron oxide are largely or entirely derived from another raw material. The raw material which furnishes the lime is usually a natural limestone—either a hard limestone, a chalk, or a marl—but occasionally an artificial product is used, such as the chemically precipitated lime carbonate which results as a waste or by-product of alkali manufacture. The silica, alumina, and iron oxide of the mixture are usually derived from clays or shales, more rarely from slates.

The various raw materials available for use in Portland-cement manufacture differ in composition, physical characters, and origin. As to *composition*, they may be almost (*a*) purely calcareous, (*b*) a mixture of calcareous and argillaceous elements, or (*c*) almost purely argillaceous; as to *physical characters* they may be (*a*) hard and massive, like the hard limestones and slates, (*b*) soft, like the chalks and shales, or (*c*) granular or unconsolidated, like the marls, clays, alkali waste, and granulated slag. As to *origin*, they may be (*a*) natural, like limestones, marls, slates, clays, etc., or (*b*) artificial, like alkali waste and furnace slag.

TABLE 144.

CHARACTER OF PORTLAND-CEMENT MATERIALS.

	Natural.			Artificial.
	Hard.	Soft.	Unconsolidated.	Unconsolidated.
Calcareous ($CaCO_3$ over 75%)	Pure hard limestone	Pure soft limestone or pure chalk	Pure marl	Alkali waste
Argillo-calcareous ($CaCO_3$ 40 to 75%)	Hard clayey limestone (cement rock)	Soft limestone or clayey chalk	Clayey marl	Blast-furnace slag
Argillaceous ($CaCO_3$ less than 40%)	Slate	Shale	Clay	

A glance at the tabulation above will show the relative physical and chemical characters of the different raw materials. It is obvious, if 75 per cent of lime carbonate will make a good cement mixture, that any of the materials in the middle line (i.e., the Argillo-calcareous group) could be used as a basis and its composition corrected by adding either a purely calcareous material or a purely argillaceous material, as might be necessary. The cement practice in the Lehigh district is an example of this kind of mixing. But the same result could be obtained by mixing any one of the materials on the first line of the table (i.e., the Calcareous group) with any one of the argillaceous materials listed in the bottom line. This is the method followed at most plants outside of the Lehigh district. There is really little to choose between the two kinds of mixtures, for the final result is the main thing. In later pages the few differences that do exist are pointed out and the advantages and disadvantages of each type are mentioned.

In previous papers the writer has grouped, under six heads, the various combinations of raw materials at present used in the United States in the manufacture of Portland cement. This grouping is as follows:

(1) Argillaceous hard limestone (cement rock) and pure limestone.
(2) Pure hard limestone and clay (or shale).
(3) Soft (chalky) limestone and clay (or shale).
(4) Marl and clay (or shale).
(5) Alkali waste and clay.
(6) Slag and pure limestone.

The relative commercial importance of these different combinations is indicated by the figures tabulated on page 304.

Examination of the statistics there given, which have been arranged by the writer from figures given in the various volumes on "Mineral Resources of the United States", issued by the U. S. Geological Survey, will develop several facts of interest. In the first place it will be seen that the "cement-rock" type of mixture, important because of its use in the Lehigh district, is slowly decreasing in relative importance, having fallen from almost three fourths of the total product in 1898 to only a little over half the total product in 1903. In absolute number of barrels produced per year, it is of course rapidly increasing, but it is no longer the *only* type of material to be considered.

The use of marl as a cement material is also slowly decreasing in relative importance, having reached its point of maximum output in 1899, when it supplied almost one fifth of all the cement made. The hard limestones, on the other hand, have increased steadily in importance

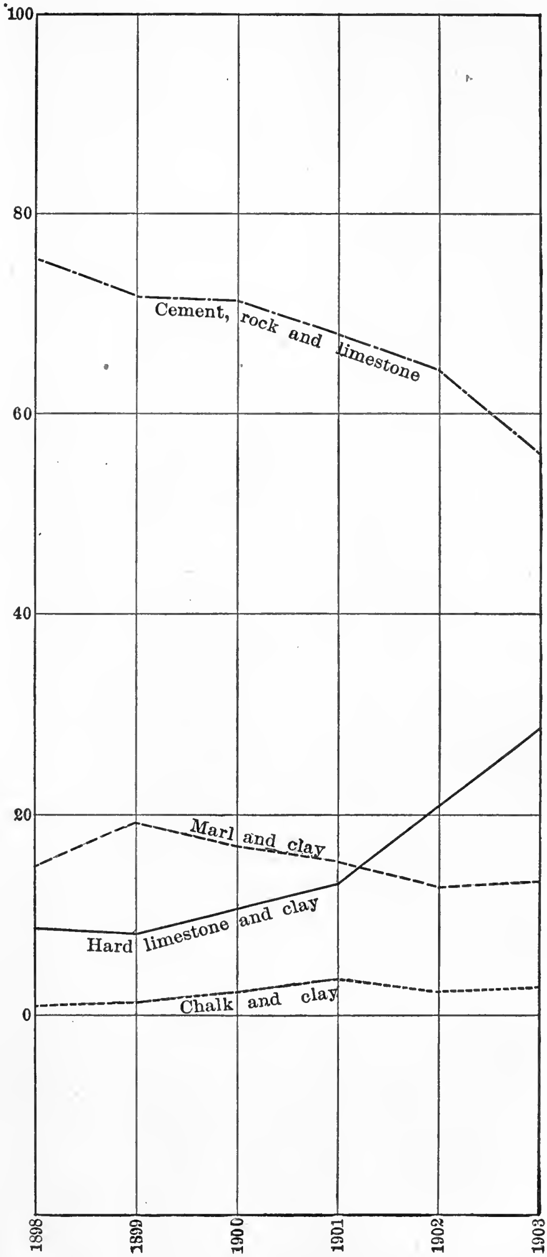

FIG. 64.—Percentage of total output produced from different raw materials.

TABLE 145.

PRODUCTION OF PORTLAND CEMENT FROM VARIOUS MATERIALS.

Year.	Type 1. Argillaceous Limestone (Cement Rock) and Pure Limestone.		Type 2.* Marl and Clay.		Type 3. Soft Limestone (Chalk) and Clay.		Type 4.† Hard Limestone and Clay.	
	Barrels.	Per Cent of Total.	Barrels.	Per Cent of Total.	Barrels.	Per Cent of Total.	Barrels.	Per Cent of Total.
1898	2,682,304	74.9	545,372	15.2	39,000	1.1	315,608	8.8
1899	4,010,132	70.9	1,095,934	19.4	88,200	1.6	458,000	8.1
1900	5,919,629	70.3	1,444,797	17.1	184,400	2.2	874,715	10.4
1901	8,503,500	66.8	2,001,200	15.8	495,752	3.9	1,710,773	13.5
1902	10,923,922	63.6	2,214,519	12.9	372,413	2.2	3,673,790	21.3
1903	12,493,694	55.7	3,052,946	13.6	457,813	2.4	6,338,520	28.3

* Including also the product from alkali waste and clay.
† Including also the product from slag and limestone.

from 1898, when they produced less than one tenth of the total output, to 1903, when they produced almost three tenths. The soft chalky limestones show little increase and are still unimportant producers, though the writer believes that they offer brilliant possibilities.

Valuation of Deposits of Cement Materials.

Determining the possible value for Portland-cement manufacture of a deposit of raw material is a complex problem, depending upon a number of distinct factors, all of which must be given due consideration. The more important of these factors are:

1. Chemical composition of the material.
2. Physical character of the material.
3. Amount of material available.
4. Location of the deposit with respect to transportation routes.
5. Location of the deposit with respect to fuel supplies.
6. Location of the deposit with respect to markets.

Ignorance of the respective importance of these factors frequently leads to an overestimate of the value of a deposit of raw material. Their effects may be briefly stated as follows:

1. **Chemical composition.**—The raw material must be of correct chemical composition for use as a cement material. This implies that the material, if a limestone, must contain as small a percentage as possible of magnesium carbonate. Under present conditions 5 or 6 per cent is the maximum permissible. Free silica in the form of chert, flint,

or sand must be absent, or present only in small quantities—say 1 per cent or less. If the limestone is a clayey limestone, or "cement rock", the proportion between its silica and its alumina and iron should preferably fall within the limits

$$\frac{SiO_2}{Al_2O_3+Fe_2O_3}>2:\frac{SiO_2}{Al_2O_3+Fe_2O_3}<3.5.$$

A clay or shale should satisfy the above equation, and should be free from sand, gravel, etc. Alkalies, sulphides, and sulphates should, if present, not exceed 3 per cent or so.

2. **Physical character.**—Economy in excavation and crushing requires that the raw materials should be as soft and as dry as possible.

3. **Amount available.**—A Portland-cement plant running on dry raw materials, such as a mixture of limestone and shale, will use approximately 20,000 tons of raw material per year per kiln. Of this about 15,000 tons are limestone and 5000 tons shale. Assuming that the limestone weighs 160 lbs. per cubic foot, which is a fair average weight, each kiln in the plant will require about 190,000 cubic feet of limestone per year. As the shale or clay may be assumed to contain considerable water, a cubic foot will probably contain not over 125 lbs. of dry material, so that each kiln will also require about 80,000 cubic feet of shale or clay.

A cement-plant is an expensive undertaking, and it would be folly to locate a plant with less than a twenty years' supply of raw material in sight. This would require that, to justify the erection of a cement-plant on any property,

For each kiln of the proposed plant, there must be in sight at least 3,800,000 cubic feet of limestone and 1,600,000 cubic feet of clay or shale.

4. **Location with respect to transportation routes.**—Portland cement is, for its value, a bulky product, and is therefore much influenced by the subject of transportation routes. To locate a plant on only one railroad, unless the railroad officials are financially connected with the cement-plant, is simply to invite disaster. At least two transportation routes should be available, and it is best of all if one of these be a good water route.

5. **Location with respect to fuel supplies.**—Every barrel (380 lbs.) of Portland cement marketed implies that at least 200 to 300 lbs. of coal have been used in the power-plant and the kilns. In other words, each kiln in the plant will, with its corresponding crushing machinery, use up from 6000 to 9000 tons of coal per year. The item of fuel cost is therefore highly important, for in the average plant about 30 to 40

per cent of the total cost of the cement will be chargeable to coal supplies.

6. **Location with respect to markets.**—In order to secure an established position in the trade, a new cement-plant should have (*a*) a local market area, within which it may sell practically on a non-competitive basis, and (*b*) easy access to a larger though competitive market area.

All of these factors should receive due consideration in deciding on the erection of a cement-plant. The summary just given is merely in the nature of a preliminary note, for these points are taken up in more detail in later chapters, particularly in those devoted to the various raw materials and to the costs of manufacture. The prospecting, examining, and sampling of deposits of limestones, marls, clays, and shales will be taken up in the chapters immediately following.

CHAPTER XXIII.

LIMESTONES.

The Portland-cement materials which are discussed in this and the following chapters (XXIV, XXV) under the names of pure hard limestone, chalk, argillaceous limestone, or "cement rock", and marl, agree in that they are all forms of limestones, though they differ sufficiently in their physical, chemical, and economic characters to be discussed separately and under different names. In order to avoid unnecessary repetition, no general discussion of limestone will be presented here, but reference should be made to Chapter VI, where the origin, varieties, composition, and properties of limestones are described in detail. In the present chapter these general facts will be briefly summarized, and certain features common to all the types of limestone used in Portland-cement manufacture will be noted, after which these different types will be separately discussed.

Limestones in General.

Varieties and origin.—Limestones are rocks composed largely or entirely of lime carbonate, or of lime carbonate with magnesium carbonate. Though one or both of these carbonates will necessarily be the principal ingredients in the rock, various impurities may occur. In addition to the chemical differences which are thus caused between different samples or kinds of limestone, they may also differ in their physical characters, or in their methods of origin, or in both of these points.

Limestones are primarily formed by the deposition of lime carbonate from sea- or lake-water which carries this salt in solution. This deposition may be direct, caused by chemical processes, or it may be effected through the agency of living organisms. *Travertine* and *tufa* are chemically deposited limestones formed by surface waters. Molluscs are able to abstract lime carbonate from sea-water and utilize it in the formation of their shells. On the death of the animals, these shells sink to the sea-bottom and thus aid in the formation of calcareous deposits. Microscopic organisms acting in this way are the cause of the formation of *chalk*, as noted later (p. 318). Vegetable life, acting in a more indirect way, appears to be an important agency in the deposition of *marl* (p. 338). Ordinary limestones may have originated in any of the ways noted above. After their formation, if subjected to sufficient heat and pressure, normal limestones may be converted into *crystalline limestones* or *marbles*.

All the varieties of limestone above named may vary in composition and degree of purity within wide limits.

Composition of limestones.—The term limestone is used, in its most general sense, to include all rocks composed largely or entirely of lime carbonate, or of lime carbonate *plus* magnesium carbonate.* A limestone of ideal purity will of course consist of 100 per cent of these carbonates; but few limestones attain even approximate purity and many are very impure. As the percentage of impurities increases, the limestone becomes more and more clayey or sandy or shaly, until at last the name limestone is no longer applicable. The exact lower limit of the group it would be difficult to fix, because the change is gradual, but probably all would agree that a rock containing less than 50 per cent of carbonates can hardly be called a limestone, but should rather be termed a calcareous clay or sandstone or shale, as the case may be. In the present volume, therefore, the lower limit in composition of limestones will be accepted as that above noted—i.e., 50 per cent of carbonates.

As the average composition of a good Portland-cement mixture is about three fourths lime carbonate and one fourth clayey matter, it is obvious that such a composition could be secured either by mixing a pure limestone and a pure clay in the proportions of about three parts limestone and one part clay, or by starting with a clayey limestone carrying, say, 60 to 85 per cent lime carbonate and adding enough clay or pure limestone to bring this percentage up or down to the required 75 per cent. The "cement rock" of the Lehigh district is an example of a highly argillaceous limestone, usually too low in lime carbonate to be a good Portland-cement material of itself and requiring the addi-

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* When discussing Portland-cement materials, the term "limestone" may be still further restricted so as to entirely exclude the highly magnesian limestones. At present all the Portland cement made is kept as low in magnesia as possible, because of the fear that this ingredient may do some harm to the cement. As a cement carrying over 4 per cent of magnesia (MgO) would be hard to market, a limestone carrying over 6 to 8 per cent of magnesium carbonate ($MgCO_3$) can hardly be classed as a possible Portland-cement material at present.

tion of a relatively small percentage of pure limestone. At a few Lehigh district quarries, however, the "cement rock" is a little too high in carbonate, rather than too low, so that it requires the addition of clay and not of limestone.

In the present volume the term "cement rock" will be used to cover clayey limestones low in magnesia and carrying from 50 to 80 per cent or so of lime carbonate, while limestones higher than 80 per cent in carbonate will be called for convenience "pure limestones".

Impurities of limestone.—Whether a limestone consists entirely of calcium carbonate or carries more or less of magnesium carbonate in addition, it may also contain a greater or lesser amount of distinct impurities. From the point of view of the Portland-cement manufacturer, the more important of these impurities are silica, alumina, iron, alkalies, and sulphur, all of which have a marked effect on the value of the limestone as a cement material. These impurities will therefore be discussed in the order in which they are named above.

The silica in a limestone may occur either in combination with alumina as a clayey impurity or not combined with alumina. As the effect on the value of the limestone would be very different in the two cases, they will be taken up separately.

Silica alone.—Silica, when present in a limestone containing no alumina, may occur in one of three forms, and the form in which it occurs is of great importance in connection with cement-manufacture.

(1) In perhaps its commonest form, silica is present in nodules, masses, or beds of flint or chert. Silica occurring in this form will not readily enter into combination with the lime of a cement mixture, and a cherty or flinty limestone is therefore almost useless in cement-manufacture.

(2) In a few cases, as in the hydraulic limestone of Teil, France, a large amount of silica is present and very little alumina, notwithstanding which the silica readily combines with the lime on burning. It is probable that in such cases the silica is present in the limestone in a very finely divided condition, or possibly as hydrated silica, possibly as the result of chemical precipitation or of organic action. In the majority of cases, however, a highly siliceous limestone will not make a cement on burning unless it contains alumina in addition to the silica.

(3) In the crystalline limestones (marbles) and less commonly in uncrystalline limestones, whatever silica is present may occur as a complex silicate in the form of shreds of mica, hornblende, or other silicate mineral. In this form silica is somewhat intractable in the kiln and mica and other silicate minerals are therefore to be regarded as

inert and useless impurities in a cement rock. These silicates will flux at a lower temperature than pure silica and are thus not so troublesome as flint or chert. They are, however, much less serviceable than if the same amount of silica were present in combination with alumina as a clay.

Silica with alumina.—Silica and alumina, combined in the form of clay, are common impurities in limestones, and are of special interest to the cement manufacturer. The best-known example of such an argillaceous limestone is the cement rock of the Lehigh district of Pennsylvania. Silica and alumina, when present in this combined form, combine readily with the lime under the action of heat, and an argillaceous limestone therefore forms an excellent basis for a Portland-cement mixture.

Iron.—Iron when present in a limestone occurs commonly as the oxide (Fe_2O_3) or sulphide (FeS_2); more rarely as iron carbonate or in complex silicate. Iron in the oxide, carbonate, or silicate forms is a useful flux, aiding in the combination of the lime and silica in the kiln. When present as a sulphide in the form of the mineral pyrite it is to be avoided in quantities over 2 or 3 per cent.

Alkalies.—Soda and potash occur usually in small percentages and most commonly in the looser-textured limestones. It is probable that these alkalies are largely driven off in the kiln, so that they do no particular harm to the cement. If the total amount of alkalies is above 5 per cent, however, a sufficient amount will be carried over into the cement to cause trouble; and raw materials carrying more than 5 per cent of soda and potash together should therefore be looked upon with suspicion, if not absolutely rejected.

Sulphur.—Sulphur may occur combined with lime as lime sulphate, or combined with iron as the mineral pyrite. In either case it is an injurious impurity, and the presence of over 1 to 1½ per cent of total sulphur should cause the rejection of the raw material.

Physical characters of limestones.—In texture, hardness, and compactness the limestones vary from the loosely consolidated marls through the chalks to the hard, compact limestones and marbles. Parallel with these variations are variations in absorptive properties and density. The chalky limestones may run as low in specific gravity as 1.85, corresponding to a weight of, say, 110 lbs. per cubic foot, while the compact limestones commonly used for building purposes range in specific gravity between 2.3 and 2.9; corresponding approximately to a range in weight of from 140 to 185 lbs. per cubic foot.

From the point of view of the Portland-cement manufacturer these variations in physical properties are of economic interest chiefly in their bearing upon two points: the percentage of water carried by the limestone as quarried, and the ease with which the rock may be crushed and pulverized. To some extent the two properties counterbalance each other, for the softer the limestone the more absorbent it is likely to be. These purely economic features will be discussed in more detail in later chapters.

Effect of heating on limestone.—On heating a non-magnesian limestone to or above 750° F., its carbon dioxide will be driven off, leaving quicklime (calcium oxide, CaO). If a magnesian limestone be similarly treated, the product would be a mixture of calcium oxide and magnesium oxide (MgO). The rapidity and perfection of this decomposition can be increased by passing steam or air through the burning mass. In practice this is accomplished either by the direct injection of air or steam, or more simply by thoroughly wetting the limestone before putting it into the kiln.

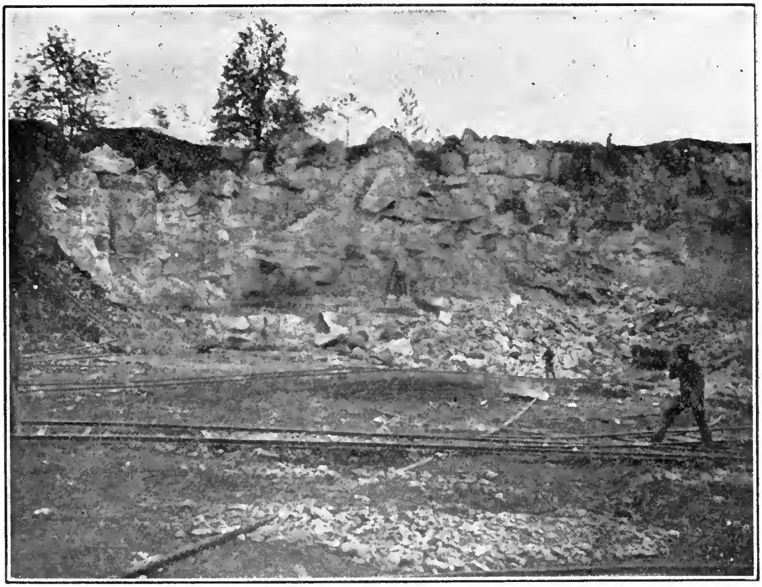

Fig. 65.—Working thick limestone-bed.

If, however, the limestone contains an appreciable amount of sillca, alumina, and iron, the effects of heat will not be of so simple a character. At temperatures of 800° C. and upwards these clayey impurities will combine with the lime oxide, giving silicates, aluminates, and related salts of lime. In this manner a natural cement will be produced. An artificial mixture of certain and uniform composition burned at a higher temperature will give a Portland cement the details of whose manufacture are discussed in the present section of this book.

Pure Hard Limestones.

Under this heading are grouped limestones of normal hardness (excluding the soft chalky limestones and the marls) which carry no less than 80 per cent of lime carbonate and less than 6 per cent of magnesium carbonate. Limestones carrying less than 80 per cent of lime carbonate are described in the next chapter under the heading of Cement Rock. The boundary between the two classes is of course an arbitrary limit, and 80 per cent of $CaCO_3$ has been selected for convenience. As a matter of fact, most of the limestones used in cement-plants are much purer than the lower limit above fixed, ranging usually from 90 to 95 per cent of lime carbonate.

Soon after the American Portland-cement industry had become fairly well established in the Lehigh district, attempts were made in New York State to manufacture Portland cement from a mixture of pure limestone and clay. These attempts were not commercially successful, and although their lack of success was not due to any defects in the limestone used, a certain prejudice arose against the use of the hard limestones. In recent years, however, this has disappeared, and a very large proportion of the American output is now made from mixtures of limestone with clay or shale. (See page 304 for comparative figures.) This reestablishment in favor of the hard limestone is doubtless due in great part to recent improvements in grinding machinery, for the purer limestones are usually much harder than argillaceous limestones like the Lehigh district "cement rock".

Composition of hard limestones actually used.—In Table 146 analyses of a large number of limestones used at American cement-plants are given. On examination it will be seen that most of these limestones range from 49 to 54 per cent of lime (CaO) and thus represent quite pure rocks, since a theoretically pure limestone composed entirely of lime carbonate ($CaCO_3$) will contain only 56 per cent of lime (CaO), the remaining 44 per cent being carbon dioxide (CO_2). With few exceptions the limestones analyzed carry less than 1 per cent of magnesia (MgO). Their sulphur percentages are also low, which appears to be more commonly the case in dealing with a hard limestone than when a soft limestone or marl is in question. The same may be said in regard to alkalies.

In prospectuses and in the reports of "cement experts", analyses of limestones averaging 98 or 99 per cent of lime carbonate are quite common, but in real life a quarry that will steadily turn out limestone 94 per cent pure is about as good as can be hoped for. With a limestone of this degree of purity little attention need be paid to the character of the remaining 6 per cent of impurities. But when a limestone carrying 90 per cent or less of lime carbonate (equivalent to about 50 per cent of lime) is in use or under consideration, the character of the impurities becomes of the first importance.

Of course objectionable percentages of sulphur compounds or magnesia would be enough to debar a limestone from use, but even when the impurity consists of clayey matter (silica, alumina, and iron oxide) its exact composition is a matter of importance and should be carefully studied. The matter of interest is the ratio given for the formula

$$\frac{\text{Percentage silica } (SiO_2)}{\text{Percentage alumina } (Al_2O_3) + \text{percentage iron oxide } (Fe_2O_3)}.$$

It is to be noted that the importance of this question increases as the limestone becomes less pure. The reason for this is obvious. Suppose we are dealing with two limestones of respective composition:

	A.	B.
Lime carbonate	95.00	80.00
Silica	4.00	16.00
Alumina	0.70	2.80
Iron oxide	0.30	1.20

The ratio $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ will in each case give a value of 4.0; but the result to the cement manufacturer will be very different. If he uses limestone A, its silica-alumina ratio is of little importance, for as the limestone is very pure (95 per cent $CaCO_3$) it will require the addition of considerable clay. The silica-alumina ratio of the mix will therefore be determined by that of the clay, not by the ratio shown by the limestone; and the manufacturer can select a clay which will give whatever he considers a desirable ratio for the mix.

But if he should use limestone B, it would require but little clay, since it is already very clayey; and it would be almost impossible to find a clay sufficiently aluminous to reduce the $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ ratio much below the 4.0 which is fixed by the limestone.

For this reason it may be taken as a safe rule that when a limestone

TABLE 146.

ANALYSES OF HARD LIMESTONES USED AT AMERICAN CEMENT-PLANTS.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphur trioxide (SO_3).	Carbon dioxide (CO_2).	Water.
1	1.21	0.70	0.50	53.62	0.44	0.11	42.98	
2	0.98	0.58	0.34	54.17	0.13	0.21	42.96	
3	1.02	1.91		53.36	0.39	0.12	43.01	
4	1.93	2.37		53.15	tr.	n. d.	42.46	
5	1.46	2.15		53.62	tr.	n. d.	42.85	
6	2.12	0.28	0.50	54.06	0.77	n. d.	42.34	
7	6.06	3.92		49.46	0.91	0.10	39.06	
8	8.20	1.30		49.37	0.85	n. d.	39.72	
9	7.54	3.43		45.57	4.36	....	39.57	
10	5.06	2.32		48.29	3.66	....	41.05	
11	13.89	2.61		45.91	1.00	....	36.82	
12	5.43	1.43		52.02	1.11	....	40.24	
13	0.74	0.13		52.49	1.87	....	43.68	
14	0.89	0.38	0.25	54.48	0.36	....	43.40	
15	0.87	0.34	0.13	54.68	0.32	....	43.44	
16	0.86	0.29		55.74	0.51	....	42.76	0.04
17	1.00	0.9	2.0	51.10	1.4	....	43.5	
18	1.19	0.95	1.28	53.13	1.36	tr.	42.66	
19	1.1	1.8		51.7	2.0	0.1	43.3	
20	0.83	1.07		52.67	1.67	....	43.19	
21	1.54	2.06		52.85	0.65	....	42.23	
22	4.17	1.37		49.34	2.94	....	41.94	
23	0.95	0.50		53.94	0.91	....	43.38	
24	3.12	1.15		52.06	1.07	....	42.06	
25	0.40	0.44		54.87	0.20	....	43.34	
26	0.54	0.42		54.73	0.19	....	43.22	
27	0.24	0.38		55.46	0.26	....	43.86	
28	1.54	0.39	1.04	53.87	0.52	....		
29	3.12	0.93		52.58	0.80	0.24	42.17	
30	2.70	1.64		52.18	1.28	0.17	42.39	
31	9.72	4.20	0.48	47.11	0.66			
32	6.30	3.35		50.25	0.22			
33	7.88	4.01		48.10	0.53			
34	3.30	1.30		52.15	1.58	0.30	40.98	
35	0.06	0.63	1.03	53.86	....	....	43.20	
36	3.53	1.14		54.45	0.44	....	38.74	
37	4.20	1.61	1.90	50.66	0.73	0.23	40.60	
38	1.30	0.73	1.17	53.34	0.75	0.03	42.72	
39	9.46	2.45	2.73	45.70	0.99	1.36	36.98	
40	0.56	1.23	0.29	54.45	0.36	tr.	43.17	
41	4.50	0.20	1.77	49.31	0.75	0.06	40.54	2.59
42	4.14	0.21	1.77	50.16	0.42	0.20	39.87	2.03
43	2.31	0.24	1.18	52.04	0.43	0.17	41.72	1.65
44	5.52	2.97		49.66	0.78			
45	n. d.	n. d.	n. d.	54.3	0.7	....	43.63	

1–5. Pacific P. C. Co., Suisun, Calif. C. J. Wheeler, analyst.
6. Southern States P. C. Co., Rockmart, Ga. J. F. Davis, analyst.
7. Chicago P. C. Co., Oglesby, Ill. Quoted in manufacturers' circular.
8. Marquette C. Co., Oglesby, Ill. 20th Ann. Rep. U. S. G. S., pt. 6, p. 544.
9–12. German-American P. C. Works, La Salle, Ill. W. E. Prüssing, analyst.
13. Lehigh P. C. Co., Mitchell, Ind. F. W. Clarke, analyst.

carries less than 90 per cent of lime carbonate it should give a value of between 2.25 and 3.0 for the ratio $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$. These are comfortable limits, and will give the manufacturer considerable latitude in his choice of a clay to mix with it.

FIG. 66.—Working heavy horizontal bed of limestone.

Prospecting and examining limestone deposits.—The prospector looking for a deposit of good limestone, or the engineer engaged to report on a deposit already located, should both realize that much trouble can be avoided if they will first familiarize themselves with

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14–15. Bedford P. C. Co., Bedford, Ind. A. W. Smith, analyst. 20th Ann. Rep. U. S. Geol. Survey, pt. 6, p. 381.
16. Iola P. C. Co., Iola, Kansas. H. N. Stokes, analyst. Bull. 78, U. S. Geol. Survey, p. 124.
17–18. Iola P. C. Co., Iola, Kansas.
19. Kansas P. C. Co., Iola, Kansas.
20–24. Alpena P. C. Co., Alpena, Mich.
25–26. Atlas P. C. Co., Ilasco, Mo.
27. Atlas P. C. Co., Ilasco, Mo. E. Davidson, analyst.
28. Catskill P. C. Co., Smith's Landing, N. Y.
29–30. Helderberg P. C. Co., Howe's Cave, N. Y. Black, analyst.
31–33. Cayuga P. C. Co., Portland Point, N. Y. J. H. McGuire, analyst.
34. Glens Falls P. C. Co., Glens Falls, N. Y. Mineral Industry, vol. 6, p. 97.
35. Ironton P. C. Co., Ironton, Ohio. C. D. Quick, analyst.
36. Alma P. C. Co., Wellston, Ohio. 21st Ann. Rep. U. S. Geol. Survey, pt. 6, p. 402.
37–39. Diamond P. C. Co., Middle Branch, Ohio. E. Davidson.
40. Wellston P. C. Co., Wellston, Ohio. W. S. Trueblood, analyst.
41–44. Crescent P. C. Co., Wampum, Pa. Robertson Bros., analysts. Report Q. Q., Penna. Geol. Surv., p. 107.
45. Virginia P. C. Co., Craigsville, Va. Cement Industry, p. 235.

the work that has been done by geologists in the areas under consideration. Most States now have geological surveys, and there are few important limestone deposits that have not been located and examined by these organizations or by the Federal survey. Numerous reports * on these subjects have been issued by State or Federal Geological Surveys, and these reports can usually be obtained free or at a merely nominal price on application to the proper officials. If such a report can be obtained covering the area to be examined it will do away with a lot of preliminary work on the part of the prospector or engineer.

Preliminary Examination.—In commencing work, it is desirable to prepare a rough map of the area. For this purpose high accuracy is not required, and a pocket compass or Brunton compass, with a Locke level, and a small protractor will be the only instruments required. With these a map can be made and plotted on a scale of 50 or 100 feet to the inch, distances being measured by pacing. The location of any natural outcrop, pits, wells, road or railroad cuts, and streams should be shown on the map, and their relative elevations ascertained as exactly as possible. When the rocks are lying almost horizontally, the locations of the outcrops are of far less importance than their elevations.

If there are sufficient good exposures of the rock, in either natural or artificial cuts, samples should be collected from these outcrops. The weathered part of the rock should be rejected, care being taken that the samples represent the fresh, undecomposed rock. When the natural exposures are not satisfactory, it will be necessary to secure samples by trenches, pits, or boring.

Most of the limestones with which the cement manufacturer may have to deal occur in beds or layers which are practically horizontal In the Appalachian and other disturbed districts, however, the beds. may be tilted to a considerable angle with the horizontal, and in rare cases they may even be almost vertical. Usually samples from different parts of the same bed (within reasonable distances of each other) will be very similar in composition; but, on the contrary, two adjoining beds may differ greatly from each other.

In sampling, therefore, it is desirable to collect at least one specimen from each bed or layer, noting the thickness and position of the bed. Even thin beds should not be neglected, for a 4-inch layer of highly magnesian rock might prove a serious drawback to the economical working of the quarry if its presence were unsuspected.

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* See reference lists on pp. 92–94.

When the beds are horizontal or nearly so a stream gorge or road cut may furnish a good idea of the character of the different beds. In default of such an exposure, it will be necessary to sink test pits to the rock, unless it is exposed conveniently at the surface, and then secure samples from various depths by drilling. Whenever possible the diamond-drill is the most satisfactory exploring device, for it is practically an automatic sampler.

When the beds are steeply inclined, a trench cut across at right angles to the bedding will expose a series of beds and enable each to be sampled.

If the beds are horizontal or nearly so, and the various samples show little difference in composition, such a preliminary examination as is described above may be all that is required. In case the rock-beds dip at high angles, or if folds or faults are suspected, it will be safest to call in a geologist or mining engineer as associate. If the analyses disagree markedly, it will be advisable to undertake a more detailed examination of the area.

Detailed Mapping and Sampling.—A much more detailed examination is always desirable before the actual erection of the plant is commenced. Such an examination will decide the best possible location for the quarry, and should also give data which will aid in keeping a uniform mix.

For these purposes a contour map, with 1-, 5-, or 10-foot contours, according to the slope, on a scale of 25 feet to the inch, should be carefully prepared. The area to be examined should be laid out in 25- or 50-foot squares and their corners marked and numbered to correspond to their locations on the map. At least three good points should be selected as permanent bench-marks, far enough away from the prospective quarry-site as not to be disturbed by excavation or blasting, and the locations and elevations of these points should be carefully determined and placed on the map.

Sampling should now be taken up carefully. For final work this can be done satisfactorily only with the diamond drill. Drill-holes should be put down at every corner of the 50-foot squares. Each 5 feet of the core should be sampled and analyzed separately, to a depth of at least 50 feet. If the rock dips steeply, or if for any other reason a deep, narrow quarry seems probable, the drilling should be continued to 200 feet. If the cores from adjacent bore-holes give closely similar analyses, closer drilling is not necessary. But if two samples taken at the same depth from two adjoining holes show differences of more than 3 per cent in their lime carbonate, or more than 1½ per cent in silica, alumina, iron oxide, or magnesium carbonate, it will be best to drill at the intermediate 25-foot point.

With the data thus obtained operations can be conducted with some confidence. Sections should be plotted to correspond to each row of drill-holes, and at the proper vertical points the drill record should be shown graphically, using different colors or conventions to distinguish rocks of different composition. The direction and amount of dip or slope of the rock-beds can be determined from observation of natural outcrops; and this will guide the engineer in drawing lines on the sections to connect the different borings.

The sections or profiles will serve as a basis for determining the amount and location of the different grades of rock. In this connection it will be safe to assume a weight of 160 lbs. per cubic foot for limestone in the quarry, and to recollect that *one rotary kiln will use about 190,000 cubic feet of limestone per year.* This would correspond to a thickness of about 4½ feet, over one acre, per year per kiln.

Chalk and Other Soft Limestones.

Chalk, properly speaking, is a pure carbonate of lime composed of the remains of the shells of minute organisms, among which those of Foraminifera are especially prominent. The chalks and soft limestones discussed in this chapter agree not only in having usually originated in this way, but also in being rather soft and therefore readily and cheaply crushed and pulverized. As Portland-cement materials they are therefore almost ideal. One defect, however, which to a small extent counterbalances their obvious advantages is the fact that most of these soft, chalky limestones absorb water quite readily. A chalky limestone which in a dry season will not carry over 2 per cent of moisture as quarried may in consequence of prolonged wet weather show as high as 15 or 20 per cent of water. This difficulty can of course be avoided if care be taken in quarrying to avoid unnecessary exposure to water and, if necessary, to provide facilities for storing a supply of the raw materials during wet seasons.

Origin of chalk.—The term chalk is properly applied to a fine-grained and usually very pure limestone, formed largely or entirely of the calcareous shells of microscopic organisms. These shells are chiefly of the minute Foraminifera, though equally small and smaller calcareous particles of various shapes also occur. Calvin describes * a section of chalk from Iowa as follows:

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* Reports Iowa Geological Survey, vol. 3, p. 224. 1895.

"In thin sections under the microscope the unbroken shells of Foraminifera are very conspicuous. They lie in close proximity to each other, and their inflated chambers, filled with crystals of calcite, sometimes occupy more than one third the area of the entire field. It is certain that more than one fourth, and in some instances more than one third, of the volume of the chalk is composed of foraminiferal shells still practically entire. The matrix in which the shells are embedded is made up of a variety of objects, the most numerous and the most conspicuous under proper amplification being the circular or elliptical calcareous discs known as coccoliths. The small rodlike bodies to which the name rhabdoliths has been applied are not very common, although their pressure is easily detected with a moderately high-power objective. Mingled with coccoliths and rhabdoliths are numerous fragments that are evidently the débris resulting from comminution of foraminiferal shells. When the chalk is treated with acid there remains a small amount of insoluble matter consisting of clay, fine grains of quartz sand, minute pebbles not exceeding 5 millimeters in diameter, and a very few internal casts of the chambers of Foraminifera. Nearly all the foraminiferal shells have the chambers filled with calcite; a few have these cavities still empty; but in a small number of cases the chambers were filled with an opaque, insoluble mineral, probably silica deeply stained with iron oxide, that remains as perfect internal casts after the shell has been dissolved in acid. The amount and composition of the residuum varies with the purity of the chalk. In some samples it scarcely exceeds 1 per cent, in others it is equal to 10 per cent."

Chalk was probably deposited in deep, quiet water little affected by débris from the land. At present material of exactly similar type is being formed in the deeper portions of the North Atlantic and other oceanic basins.

Distribution of chalk and soft limestones.—Both the true chalks and the other soft limestones here considered are of comparatively recent geologic age, occurring only in Cretaceous or Tertiary rocks. There is also a certain geographic unity apparent, for both types occur only along the Atlantic and Gulf coasts and in the Western States. For detailed information regarding the distribution of these rocks reference should be made to the papers and reports listed on page 322. In the present place only a summary can be given covering the more important features of the subject.

The true chalks occur only in formations of Cretaceous age in certain Southern and Western States. The principal chalk deposits available for use in Portland-cement manufacture occur in three widely separated areas occupying respectively (*a*) parts of central Alabama and northeastern Mississippi, (*b*) southwestern Arkansas and central Texas, and (*c*) parts of Iowa, Nebraska, North and South Dakota, Colorado, and other States of the Great Plains region. Though the chalk is in all these areas of approximately the same age and character, the formations containing it have been given different names—i.e., the Selma chalk, in Alabama and Mississippi; the Whitecliffs chalk, in Arkansas; the Austin chalk, in Texas; and the Niobrara chalk, in the Great Plains region.

In addition to the true chalks, soft limestones of Tertiary age occur in all the Atlantic and Gulf coast States from Virginia to Mississippi inclusive, as well as in California. These are the materials commonly described as "marls" in the older geological reports, though they are in no way related to the fresh-water marls now so largely used in Portland-cement manufacture, discussed in Chapter XXV.

Physical Properties.—When dry, the chalks and soft limestones, are commonly considerably lighter than the hard limestones. As noted on a previous page, the chalky limestones may run as low in specific gravity as 1.85, corresponding to a weight of about 110 lbs. per cubic foot, while the hard, compact limestones in common use range in specific gravity from 2.3 to 2.9, corresponding approximately to a range in weight of from 140 to 185 lbs. per cubic foot.

The low weight above quoted is, however, exceptional, and the soft limestones may be expected to range between 125 and 150 lbs. per cubic foot when dry. They are usually very porous, however, and but brief exposure to water will increase their weight and moisture content remarkably. This, indeed, is their single defect from the point of view of the cement manufacturer, for during a rainy season or with a badly drained quarry he may have to handle a material carrying 15 or 20 per cent of moisture.

Otherwise they are admirable cement materials, being soft and easily quarried and ground.

Composition of chalks and soft limestones used in cement-plants.—In composition the chalks and other soft limestones vary from a rather pure lime carbonate low in both magnesia and clayey matter to an impure clayey limestone of about the composition of the Lehigh district cement rock. Magnesium carbonate is rarely present in quantities of over 2 or 3 per cent, but alkalies, sulphur, and phosphoric acid may occur in sufficient percentages to require careful considerations.

TABLE 147.

ANALYSES OF PURE CHALKS USED IN AMERICAN CEMENT-PLANTS.

	1.	2.	3.	4.	5.	6.	7	8.
Silica (SiO_2)	5.33	4.42	6.09	3.83	4.14	2.15	5.77	2.22
Alumina (Al_2O_3)	3.03	2.21	3.52	2.31	1.81	2.72	2.14	0.92
Iron oxide (Fe_2O_3)		1.03	1.20		2.72			0.18
Lime (CaO)	50.53	53.36	49.24	52.16	51.00	52.48	50.45	54.08
Magnesia (MgO)	0.55	n. d.	n. d.	0.14	tr.	n. d.	0.28	0.10
Alkalies (K_2O,Na_2O)	n. d.	n. d.	n. d.	....	tr.	n. d.	n. d.	n. d.
Sulphur trioxide (SO_3)	n. d.	n. d.	n. d.	0.20	0.50	n. d.	n. d.	
Carbon dioxide (CO_2)	50.30	n. d.	n. d.	41.64	39.99	n. d.	40.00	42.50
Water	n. d.	n. d.	n. d.		n. d.	n. d.	n. d.	

1. Whitecliffs P. C. Co., Whitecliffs, Ark. 18th Ann. Rep., U. S. Geol. Survey, pt. 5, p. 1174.
2–3. " " " " Trans. Amer. Institute Mining Engrs., vol. 21, p.
4. Western P. C. Co., Yankton, S. D. C. B. McVay, analyst.
5. " " " " Mineral Industry, vol. 1, p. 52.
6. " " " " " " vol. 6, p. 97.
7. Alamo Cement Works, San Antonio, Texas. 22d Ann. Rep. U. S. Geol. Survey, pt. 3, p. 737.
8. Almendares P. C. Co., Marinao, Cuba. Engineering Record, vol. 49, p. 36.

TABLE 148.

ANALYSES OF CLAYEY CHALKS USED IN AMERICAN CEMENT-PLANTS.

Silica (SiO_2)	9.88	7.64	12.13	13.32
Alumina (Al_2O_3)	6.20	7.62	4.17	8.74
Iron oxide (Fe_2O_3)			3.28	
Lime (CaO)	43.19	45.20	42.04	41.41
Magnesia (MgO)	0.52	0.59	0.44	0.67
Sulphur trioxide (SO_3)	n. d.	1.62	n. d.	0.27
Carbon dioxide (CO_2)	34.49	36.06	33.51	33.26
Water	5.72	1.36	n. d.	n. d.

Examining chalk deposits.*—The chalk deposits of most of the States have been carefully mapped by geological surveys, and much time will be saved by procuring and studying the proper reports. These will give general data on the distribution and character of the chalk formations.

In examining chalk deposits it is well to recollect that they are always found in thick and almost horizontal beds. Stream ravines usually give good natural sections, which will serve to give a preliminary idea of the character of the rock. In securing samples, the earth-auger gives satisfactory results in most chalk deposits, because the material is usually soft enough to be penetrated readily by this tool.

The principal impurities to be guarded against are nodules of pyrite and grains of sand, both of which are very common in many American chalk deposits.

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* See pages 315–318 for further notes on this subject.

List of references on chalks and soft limestones.—The following papers deal largely with the chalky limestones of the United States. For convenience of reference those which consider chiefly the origin and structure of chalk are marked *A*; those which describe its distribution in certain States or areas are marked *B*.

B. Branner, J. C. The cement materials of southwest Arkansas. Trans. Am. Inst. Min. Engrs., vol. 27, pp. 42–63. 1898.

A. Calvin, S. The Niobrara chalk. Proc. Amer. Assoc. Adv. Sci., vol. 43, pp. 197–217. 1895.

A. Calvin, S. Composition and origin of Iowa chalk. Reports Iowa Geological Survey, vol. 3, pp. 211–236. 1895.

A. Dawson, G. M Note on the occurrence of Foraminifera, etc., in the Cretaceous rocks of Manitoba. Canadian Naturalist, vol. 7, no. 5. 1874.

B. Eckel, E. C. Cement materials and cement industries of the United States. Bulletin 243, U. S. Geological Survey. 1905.

B. Hill, R. T. A brief description of the Cretaceous rocks of Texas and their economic value. 1st Ann. Report Texas Geological Survey, pp. 103–144. 1890.

A. B. Hill, R. T. Neozoic geology of southwestern Arkansas. Ann. Rep. Arkansas Geol. Survey for 1888, vol. 2.

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CHAPTER XXIV.

ARGILLACEOUS LIMESTONE: CEMENT ROCK.

THE term "cement rock" is here used to include all the very clayey limestones carrying from 50 to 80 per cent of lime carbonate, with correspondingly high percentages of argillaceous matter, and less than 8 per cent of magnesium carbonate. It is evident that an argillaceous limestone low in magnesia, and containing approximately 75 to 77 per cent of lime carbonate and 20 per cent or so of clayey materials (silica, alumina, and iron oxide) would be the ideal material for use in the manufacture of Portland cement; for a rock of this composition would contain within itself, mixed in the proper proportions, all the ingredients necessary for the manufacture of a good Portland. Such an ideal rock would require the addition of no other raw material, but when burnt alone would give a good cement.

This ideal cement material is, of course, never realized in practice, but certain deposits of clayey limestone approach it very closely in composition. A limestone carrying 70 or 80 per cent of lime carbonate and 20 to 30 per cent clayey matter will require the addition either of pure limestone or of clay in order to bring it to the desired composition for a Portland-cement mixture. But it will be, of itself, so *near* to the correct composition that it will need but little of the extra raw material to make it absolutely perfect. Deposits of such "cement rocks" possess important technologic advantages, and have been sought for with great industry. Many such deposits of clayey limestones, low in magnesia, occur in various parts of the United States, but few of them are well located with regard to transportation routes, fuel supplies, and markets.

The most important of these argillaceous limestone, or "cement-rock", deposits is at present that which is so extensively utilized in Portland-cement manufacture in the "Lehigh district" of Pennsylvania and New Jersey, though similar "cement rocks" occur in many other States. As the Lehigh district still produces over half of all the Portland cement manufactured in the United States, its raw materials will be described below in some detail, after which other areas of "cement rock" will be briefly noted.

Cement Rock of the Lehigh District, Pennsylvania-New Jersey.

The "Lehigh district" of the cement manufacturer has been so greatly extended in recent years that the name is now hardly applicable. Originally it included merely an area about 4 miles square, located along the Lehigh River partly in Lehigh County and partly in Northampton County, and containing the villages of Egypt, Coplay, Northampton, Whitehall, and Siegfried. The cement-plants which were early located here secured control of most of the cement-rock deposits in the vicinity, and plants of later establishment have therefore been forced to locate farther away from the original center of the district. At present the district includes parts of Berks, Lehigh, and Northampton Counties, Pa., and Warren County, N. J., reaching from near Reading, Pa., at the southwest, to a few miles north of Stewartsville, N. J., at the northeast. It forms an oblong area about 25 miles in length from southwest to northeast and about 4 miles in width. Within this area about twenty Portland-cement plants are now in operation, and the Portland cement produced in this relatively small district amounts to over half of the entire United States output.

Geology of the district.—Within the "Lehigh district" three geologic formations occur, all of which must be considered in attempting to account for the distribution of the cement materials used here. These three formations are, in descending order, the (1) Hudson shales, slates, and sandstones; (2) Trenton limestone (Lehigh cement rock); (3) Kittatinny limestone (magnesian). As all these rocks dip, in general, northwestward, the Hudson rocks occupy the northwestern portion of the district, while the cement rock and magnesian limestone outcrop in succession farther southeast.

Hudson shale.—This series includes very thick beds of dark-gray to black shales, with occasional thin beds of sandstone. In certain localities, as near Slatington and Bangor, Pa., and Newton, N. J., these shales have been so altered by pressure as to become slates, the quarrying of which now supports a large roofing-slate industry.

The composition of the typical shales and slates of the Hudson formation is well shown by the following analyses (Table 149).

The geographic distribution of the Hudson shales and slates in the Lehigh district can be indicated only approximately without the presentation of a geologic map of the area. They cover practically all of Northampton, Lehigh, and Berks counties north of a line passing through Martins Creek, Nazareth, Bath, Whitehall, Ironton, Guthsville, Monterey, Kutztown, Molltown, and Leesport.

The rocks of the Lehigh district have a general dip to the northwest,

TABLE 149.

ANALYSES OF HUDSON SHALE AND SLATE IN PENNSYLVANIA AND NEW JERSEY.

	1.	2.	3.	4.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silica (SiO_2)	68.62	68.00	56.60	* 76.22
Alumina (Al_2O_3)	12.68	14.40	21.00	13.05
Iron oxide (Fe_2O_3)	4.20	5.40	5.65	
Lime (CaO)	1.31	2.68	3.42	2.67
Magnesia (MgO)	1.80	1.51	2.30	0.93
Alkalies	3.73	0.11	0.50	n. d.
Carbon dioxide (CO_2)	2.99	2.30	2.20	n. d.
Water (H_2O)	4.47	2.70	3.00	n. d.

* Insoluble.

1. East Bangor, Pa. 20th Ann. Rep. U. S. Geol. Survey, pt. 6, p. 436.
2. 1 mile northwest of Colemanville, N. J. Geology New Jersey, 1868, p. 136.
3. Delaware Water Gap, N. J. Geology New Jersey, 1868, p. 136.
4. Lafayette, N. J. Rept. New Jersey State Geol. for 1900, p. 74.

though there are numerous local exceptions to this rule. The lowest beds of the Hudson series, therefore, are those which outcrop along the southern boundary of the formation, as above outlined. These lowest beds carry much more lime and less silica, alumina, and iron than the higher beds whose analyses are given in table 149. The lowest beds form a natural transition into the underlying cement rock.

Trenton limestone.—The Lehigh cement rocks, which are equivalent in age to the Trenton limestone beds of New York, are made up of a series of argillaceous limestones. The formation appears to vary in thickness from 150 feet in New Jersey to 250 feet or even more at Nazareth and on the Lehigh River. Its upper beds near the contact with the overlying Hudson shales are very shaly or slaty black limestones carrying approximately 50 to 60 per cent of lime carbonate and 40 to 50 per cent of silica, alumina, iron, etc. Lower in the formation the percentage of lime steadily increases, while that of clayey material decreases correspondingly, until near the base of the formation the rock may carry from 85 to 95 per cent of lime carbonate with only 5 to 15 per cent of impurities. This change in chemical composition is accompanied by a change in the appearance and physical character of the rock, which gradually loses its slaty fracture and blackish color as the percentage of lime increases, until near the base of the formation it is often a fairly massively bedded dark-gray limestone. Even so, it can usually be readily distinguished from the magnesian Kittatinny limestone, described below, for the cement rock is always darker than the magnesian limestone and contains none of the chert beds which are so common in the magnesian rock.

The Lehigh cement rock is never nearly so high in magnesia as is the underlying Kittatinny limestone. It does, however, carry considerable magnesia (as compared with other Portland-cement materials) throughout its entire thickness, and few analyses will show less than 4 to 6 per cent of magnesium carbonate. The following series of analyses is fairly representative of the lower, middle, and upper beds of the formation. The specimens from the upper beds, near the Hudson shales, show considerably less lime and more clayey matter than those from the lower parts of the formation.

TABLE 150.

ANALYSES OF TRENTON LIMESTONE (LEHIGH CEMENT ROCK).

	1.	2.	3.	4.	5.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silica (SiO_2)	1.83	5.03	8.38	11.90	11.71
Alumina (Al_2O_3)	.60	2.06	4.63	4.42	4.36
Iron oxide (Fe_2O_3)	.51	1.23	1.32	1.70	1.62
Lime (CaO)	53.64	49.73	45.45	44.18	43.47
Magnesia (MgO)	.81	1.02	1.34	1.18	1.82
Carbon dioxide (CO_2)	43.03	40.19	37.18	36.01	36.15

	6.	7.	8.	9.	10.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silica (SiO_2)	11.11	17.04	22.71	19.53	24.45
Alumina (Al_2O_3)	4.40	6.90	5.84	6.03	5.68
Iron oxide (Fe_2O_3)	1.91	2.13	2.13	1.70	1.57
Lime (CaO)	42.51	37.53	36.50	35.71	35.00
Magnesia (MgO)	2.89	2.17	1.69	3.33	2.21
Carbon dioxide (CO_2)	36.57	32.88	30.52	32.73	29.89

Ann. Rept. New Jersey State Geologist for 1900, p. 95.

The specimens whose analyses are given above were mostly from the vicinity of Belvidere, N. J., and, though representative in other respects, seem to have been rather lower in magnesia than the usual run of the Trenton limestone in the Lehigh district.

Kittatinny magnesian limestone.—Underlying the cement-rock series is a very thick formation consisting of light-gray to light-blue massive-bedded limestone, with frequent beds of chert. These limestones are predominantly highly magnesian, though occasionally beds of pure non-magnesian limestone will be found in the series. The magnesian beds are, of course, valueless for Portland-cement manufacture, but the pure limestone-beds furnish part of the limestone used in the Lehigh district for addition to the cement rock. An excellent example of this is furnished by the quarry near the east bank of Lehigh River, just above Catasauqua. In this quarry most of the beds are highly magnesian, and are therefore useful only for road metal and flux; but a few pure limestone beds occur, and the material from these low-magnesia beds is shipped to a neighboring cement-mill.

Numerous analyses of the highly magnesian limestones are available, from which a few typical results have been selected for insertion here. Analyses of the purer limestone, used to add to the cement rock, will be found in the table on page 329.

TABLE 151.

ANALYSES OF KITTATINNY MAGNESIAN LIMESTONE.*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silica (SiO_2)	9.9	9.9	8.8	5.5	9.8	4.9	2.0	8.0	4.1	16.9
Alumina (Al_2O_3)	1.7	1.7	0.8	1.3	3.7	6.5	8.4	5.3	1.6	1.0
Iron oxide (Fe_2O_3)										
Lime (CaO)	27.6	28.5	29.4	28.2	26.4	27.3	32.4	26.3	30.3	28.3
Magnesia (MgO)	17.9	17.3	17.8	20.2	15.1	14.6	15.5	17.4	18.3	15.3
Carbon dioxide (CO_2)	41.9	41.5	42.8	44.3	45.0	44.8	42.5	41.1	44.1	38.9

From various reports of the New Jersey Geological Survey.

1. Chandlers Island, Sussex County, N. J.
2. Sparta, Sussex County, N. J.
3. Asbury, Warren County, N. J.
4. Oxford Furnace, Sussex County, N. J.

5, 6. Clinton, Hunterdon County, N. J.
7. Pottersville, Somerset County, N. J.
8, 9. Peapack, N. J.
10. Annandale, N. J.

While all of the above analyses are from New Jersey localities, the magnesian limestone of the rest of the Lehigh district would give closely similar results.

Throughout most of the Lehigh district the practice is to mix a small amount of pure limestone with a relatively large amount of the "cement rock" or argillaceous limestone, in order to bring the lime carbonate content up to the percentage proper for a Portland-cement mixture. As above noted, all of the "cement rock" is derived from the middle part of the Trenton formation, where the beds will run from 60 to 70 per cent of lime carbonate. The pure limestone which is required to bring this material up to the necessary percentage of lime carbonate (75 per cent or so) is obtained either from the lower portion of the Trenton itself or from certain low-magnesia beds occurring in the Kittatinny formation.

In the plants located near Bath and Nazareth, however, the practice has been slightly different. In this particular area the cement-rock quarries usually show rock carrying from 75 to 80 per cent of lime carbonate. The mills in this vicinity, therefore, require practically no pure limestone, as the quarry rock itself is sufficiently high in lime carbonate for the purpose. Indeed, it is at times necessary for these plants to add clay or slate, instead of limestone, to their cement rock, in order to reduce its content of lime carbonate to the required figure. In general, however, it may be said that Lehigh practice is to mix a low-carbonate cement rock with a relatively small amount of pure limestone, and analyses of both these materials, as used at various plants in the district, are given below in Tables 152 and 153.

Character and composition of the cement rock.—The cement rock is a dark-gray to black, slaty limestone, breaking with an even fracture into flat pieces, which usually have smooth, glistening surfaces. As the percentage of lime carbonate in the rock increases—i.e., as the lower beds of the formation are reached—the color becomes a somewhat lighter gray and the surfaces of the fragments lose their slaty appearance.

The range in composition of the cement rock as used at various plants is well shown in the first eight columns of the above table. The nearer the material from any given quarry or part of a quarry approaches the proper Portland-cement composition (say 75 to 77 per cent lime carbonate) the less addition of pure limestone will be necessary. In by far the greater part of the district, as above noted, the cement rock is apt to run about 65 to 70 per cent of lime carbonate, therefore requiring the addition of a proportionate amount of limestone. Most of the quarries near Bath and Nazareth, however, have been opened on beds of cement rock running considerably higher in lime carbonate and occasionally running so high (80 per cent, etc.) as to require the addition of shale or clay rather than of pure limestone.

Character and composition of the pure limestones.—The pure limestones added to the cement rock are commonly gray and break into rather cubical fragments. The fracture surfaces show a finely granular structure quite distinct in appearance from the slaty cement rock.

In composition the limestones commonly used will carry from 90 to 96 per cent of lime carbonate, with rather less magnesium carbonate than is found in the cement rock. All of the cement-plants own and operate their own cement-rock quarries, but most of them are compelled to buy the pure limestone. When this is the case only very pure grades of limestone are purchased, but when a cement-plant owns

TABLE 152.

ANALYSES OF HIGHLY CLAYEY LIMESTONES: "CEMENT ROCK".

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron Oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon Dioxide (CO_2).	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$	Cementation Index
1	18.30	6.11	1.85	36.38	2.13	28.96	2.29	1.51
2	15.97	7.53	2.24	34.34	3.93	32.80		
3	17.32	9.11		38.59	2.05	32.55		
4	19.62	5.68		39.08	2.35	33.25		
5	16.77	6.50		41.37	n. d.	n. d.		
6	15.73	7.92		39.62	1.81	33.08	....	1.23
7	19.06	4.44	1.14	38.77	2.02	32.66		
8	22.22	7.24	0.92	35.53	2.19	30.29	2.72	
9	19.08	7.92		37.56	1.95	31.62		
10	14.20	6.14		41.51	1.56	34.47		
11	14.52	6.52		41.17	2.25	34.79		
12	15.05	9.02	1.27	39.26	1.90	32.90	1.46	
13	15.20	8.80		38.70	1.47	31.99		

TABLE 153.

ANALYSES OF PURE LIMESTONES USED FOR MIXING WITH CEMENT ROCK.

Silica (SiO_2).	Alumina (Al_2O_3).	Iron Oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Carbon Dioxide (CO_2).
3.64	0.61		52.93	n. d.	n. d.
5.56	2.40		50.47	1.00	40.73
3.02	1.90		51.55	1.46	42.08
1.98	0.70		53.31	0.97	42.94
2.14	1.46		52.84	1.05	42.64
4.50	0.82		51.50	0.66	41.19
3.40	0.70		52.53	0.61	41.94
1.02	0.48		54.60	0.53	43.47
0.08	0.40		54.90	0.61	43.80
6.1	3.5		47.21	2.35	39.64

its limestone quarry material running as low as 85 per cent of lime carbonate is often used.

Quarry practice.—In most of the cement-rock quarries of the Lehigh district the rock dips from 15° to 25°, usually to the northwest. At a few quarries, particularly in New Jersey, the dip is much steeper. The quarries are opened preferably on a side-hill, and the overlying stripping, which consists of soil and weathered rock, is removed by scrapers or shoveling. The quarry of the Lawrence Cement Company has been extended in its lower levels so as to give a tunnel through which the material is hoisted to the mill. Several other quarries have been carried straight down, until now they are narrow and deep pits, from which the material is hoisted vertically. The Bonneville Portland Cement Company's quarry is an extreme example of this type.

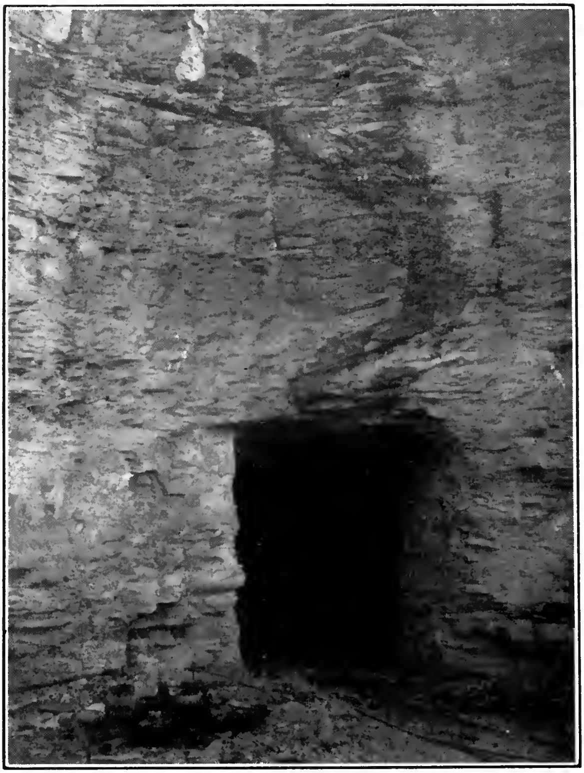

FIG. 67.—Tunnel, Lawrence Cement Co., Siegfried, Pa.

In quarries opened on a side-hill, so as to have a long and rather low working-face and a floor at the natural ground level, the rock is commonly blasted down in benches, sledged to convenient size for handling and crushing, and carried by horse carts to a point in the quarry some distance from the face where the material can be dumped into cars, which are hauled by cable to the mill. Occasionally the material is loaded at the face into small cars running on temporary tracks. The loaded cars are then drawn by horses or pushed by men to a turntable, where they are connected to the cable and hauled to the mill. While these methods seem clumsy at first sight, they are capable of little improvement. The amount of rock used every day in a large mill necessitates very heavy blasting, and this prevents permanent tracks and cableways from being laid near to the working-face.

At several quarries the loading into the cars or carts is accomplished by means of steam-shovels. The cement rock seems to be well adapted for handling by steam-shovels, but even then much sledging is necessary and the blasting operations are interfered with.

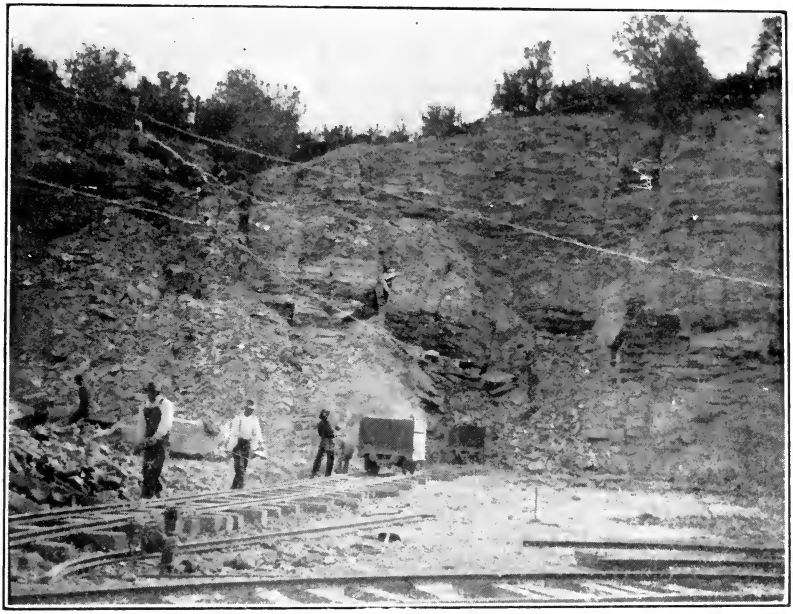

FIG. 68.—Open cut in cement rock.

Cement production of the district.—The importance of these Lehigh district cement-rock deposits is well brought out by Table 154.

Probable extension of the industry.—As noted in the earlier portion of this chapter, the cement deposits have been developed only from near Reading, Pa., to a few miles west of Stewartsville, N. J. Most of the readily accessible cement land between these points has been taken up by the cement companies or is being held at impossible prices by the owners. Under these circumstances it seems probable that few additional plants can be profitably established in the district now developed, and that the growth of the industry here will be brought about by extending the district. A few notes on the distribution of the same cement-beds in adjoining areas may therefore be of interest to those desiring to engage in the manufacture of Portland cement from materials of the Lehigh district type.

TABLE 154.

PORTLAND-CEMENT PRODUCTION OF THE LEHIGH DISTRICT, 1890–1902.

Year.	Lehigh District.		Entire United States.			Percentage of Total Product Manufactured in Lehigh District.
	Number of Plants.	Number of Barrels.	Number of Plants.	Number of Barrels.	Value.	
1890......	5	201,000	16	335,500	$439,050	60.0
1891......	5	248,500	17	454,813	1,067,429	54.7
1892......	5	280,840	16	547,440	1,152,600	51.3
1893......	5	265,317	19	590,652	1,158,138	44.9
1894......	7	485,329	24	798,757	1,383,473	60.8
1895......	8	634,276	22	990,324	1,586,830	64.0
1896......	8	1,048,154	26	1,543,023	2,424,011	68.1
1897......	8	2,002,059	29	2,677,775	4,315,891	74.8
1898......	9	2,674,304	31	3,692,284	5,970,773	72.4
1899......	11	4,110,132	36	5,652,266	8,074,371	72.7
1900......	15	6,153,629	50	8,482,020	9,280,525	72.6
1901......	16	8,595,340	56	12,711,225	12,532,360	67.7
1902......	17	10,829,922	65	17,230,644	20,864,078	62.8
1903......	19	12,324,922	75	22,342,973	27,713,319	55.2

Northeast of Stewartsville, N. J., the cement-beds outcrop at frequent intervals in the Kittatinny Valley all the way across New Jersey and a few miles into Orange County, N. Y. The exact locations of these deposits, with numerous analyses of the cement rocks, are given in the Annual Report of the State Geologist of New Jersey for 1900, pages 41–95. Many detailed maps in this report show the outcrops very precisely.

Southwestward from Reading the Trenton beds outcrop in a belt crossing Lebanon, Cumberland, and Franklin counties, Pa., passing near the tows of Lebanon, Harrisburg, Carlisle, and Chambersburg. In Maryland the Trenton rocks occur in Washington County, while in West Virginia and Virginia they are extensively developed. The distribution of these rocks in Virginia is discussed in the papers by Messrs. Bassler and Catlett, cited in the list on page 333.

Throughout this southern extension of the Lehigh rocks, the Trenton is not everywhere an argillaceous limestone, but it is frequently so, and it is always very low in magnesium carbonate. It is therefore probably safe to say that in southern Pennsylvania, Maryland, West Virginia, and Virginia the Trenton rocks are everywhere good Portland-cement materials, though in some cases they will require pure limestone, and in other places clay, to bring them to proper composition.

Cement Rocks in Other States.

Limestones sufficiently clayey to be called " cement rocks" are not by any means confined to the Lehigh district, nor even to the immediate vicinity of that fortunate area. As noted in the last chapter, cement rock exactly similar to that used in the Lehigh district occurs in other parts of Pennsylvania, in Maryland, and the Virginias. Similar clayey limestones occur southward, along the Appalachian Valley, through Tennessee and northern Georgia. In all this range, however, they have never been used as Portland-cement materials, though a natural-cement plant was erected a few years ago at Rossville, Ga., a few miles south of Chattanooga, to utilize limestones closely similar to the Lehigh rock in composition.

The following analyses show the composition of "cement rocks" used at various Portland-cement plants in the Western States, together with that of the purer limestones used for mixing.

TABLE 155.

ANALYSES OF "CEMENT-ROCK" MATERIALS FROM THE WESTERN UNITED STATES.

	Utah.		California.		Colorado.	
	Cement Rock.	Limestone.	Cement Rock.	Limestone.	Cement Rock.	Limestone.
Silica (SiO_2)	21.2	6.8	20.06	7.12	14.20	
Alumina (Al_2O_3)	8.0	3.0	10.07	2.36	5.21	
Iron oxide (Fe_2O_3)	.....	.....	3.39	1.16	1.73	
Lime carbonate ($CaCO_3$)	62.08	89.8	63.40	87.70	75.10	88.0
Magnesium carbonate ($MgCO_3$)	3.8	0.76	1.54	0.84	1.10	

In addition to the "cement rocks" noted in this chapter, it is necessary to call atention to the fact that many of the chalky limestones discussed in the following chapter are sufficiently argillaceous to be classed as "cement rocks". Because of their softness, however, all these chalky limestones will be described together.

List of references on " cement rock ".

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CHAPTER XXV.

FRESH-WATER MARLS.

Marls, in the sense in which the term is used in the Portland-cement industry, are fine-grained, friable limestones which have been deposited in the basins of existing or extinct lakes. So far as chemical composition is concerned, marls are practically pure limestones, being usually composed almost entirely of calcium carbonate. Physically, however, they differ greatly from the hard, compact rocks to which the term limestone is more commonly applied, for the marls are granular, loose, non-coherent deposits. These curious physical characters of marls, as compared with ordinary limestones, are due to the peculiar conditions under which the former have been deposited. Samples of marl from different localities will on comparison be found to exhibit considerable variations, and these arise in large part from differences in local conditions during deposition.

As explained on a later page, differences of opinion exist as to the exact cause of the formation of marl deposits. The points in controversy are of no particular practical importance, and may be disregarded in the present brief statement of facts. It may safely be said that marls are deposited in lakes by spring or stream waters carrying lime carbonate in solution. The actual deposition of the marl is in part due to purely physical and chemical causes, and in part to the direct or indirect action of animal or vegetable life. The result in any case is that a calcareous deposit forms along the sides and over the bottom of the lake, this deposit consisting of lime carbonate, mostly in a finely granular form, interspersed with shells and shell fragments.

Various uses of the term "marl".—A warning to the reader concerning other uses of the term "marl" may profitably be introduced here. The meaning above given is that in which the term marl is commonly used in the cement industry at the present day. But in geological and agricultural reports, particularly in those issued before the Portland-cement industry became prominent in this country, the term marl has been used to cover several very different substances. The following three uses of the term will be found particularly common, and must be guarded against when such reports are being examined in search for descriptions of deposits of cement materials.

1. In early days the terms "marls" and "marlytes" were used to describe deposits of calcareous shales—and often these terms were extended to cover shales which were not particularly calcareous. This use of the term will be found in many of the earlier geological reports issued by New York, Ohio, and other interior States.

2. In New Jersey and the States southward bordering on the Atlantic and Gulf of Mexico the term marl is commonly applied to deposits of soft chalky or unconsolidated limestone often containing considerable clayey and phosphatic matter. These limestones are of marine origin and not related to the fresh-water marl deposits which are the subject of the present chapter.

3. In the same States, but particularly in New Jersey and Virginia, large deposits of the so-called "green-sand marls" occur. This material is in no way related to the true marls (which are essentially lime carbonates), but consists largely of the iron silicate called glauconite, or green sand, with very small percentages of clayey, calcareous, and phosphatic matter.

The three early uses of the term "marl" above noted all agree in that they apply to deposits of marine origin, while the marls of the cement manufacturer are purely fresh-water deposits.

Occurrence of marl deposits.—Fresh-water marls occur in more or less lenticular or basin-shaped deposits of relatively small size. Their form and local character are both due to the fact that the marls were formed by deposition in lake basins. In many cases these lakes still contain water, and in some instances marl deposition is now in progress. In other cases, however, the lake has entirely disappeared, and the marl-bed now occurs in a swamp or marsh covered with peat or muck.

The disappearance of a lake in this fashion must be regarded as part of a very natural and almost invariable cycle of events. The existence of a lake at any point along a drainage system is to be considered a somewhat unnatural and temporary condition, and one which will be removed by natural causes as soon as possible. In the glaciated portion of the United States many lakes were formed at the close of the Glacial period. These lakes were due in some cases to the fact that deposits of sand and clay laid down by the glaciers had filled old valleys and dammed the streams occupying such valleys. In other cases the lake basins were formed by the irregular distribution of these glacial deposits, leaving hollows and depressions which subsequently became filled with water. In either case a lake or pond was formed, and immediately a series of natural forces were set in operation which tended to remove this lake. Of the two common methods of lake disappearance, one has but little to do with our present subject, but the other is closely connected with the history of marl deposition. The first method is the gradual deepening of the outlet by the action of its own current, resulting in the draining of the lake. The second is the filling up of the lake basin by deposits of sand, clay, marl, muck, and peat.

Origin of marl deposits.—The exact cause of the formation of marl deposits has been the subject of much investigation and discussion, particularly in the past few years, since these deposits have become of so great economic importance. For details concerning this discussion, reference should be made to the papers listed on pages 346–347, especially to those by Davis and Blatchley. In the present place only a summary of the main facts—and theories—in regard to the formation of marl deposits will be given.

Marl deposits in their present form and position are due directly or indirectly to glacial action, on which account these deposits occur almost exclusively in that portion of the country which was covered by ice during the Glacial epoch. The glaciers aided in the formation of marl deposits in two ways: first, by furnishing a large supply of finely ground calcareous material from which surface waters could take up lime carbonate in solution, and, second, by forming the lake basins in which these waters deposited their burden of lime carbonate as marl. The processes followed in the formation of marl deposits may be outlined with some confidence, though certain of the steps are still subject to discussion.

Rain-water, though theoretically pure before approaching the earth's surface, takes up a considerable percentage of carbon dioxide in passing through the atmosphere. When it reaches the surface, therefore, such rain-water is in reality a very dilute form of carbonic acid (H_2CO_3), and as such is capable of attacking limestone, taking the lime carbonate ($CaCO_3$) into solution in the form of calcium bicarbonate ($CaH_2(CO_3)_2$). Practically all natural water, including the percolating ground-water as well as spring and stream water, is therefore able to change itself with lime carbonate if some source of that compound presents itself. In the present marl districts such a source is not far to seek, for from New York to Michigan limestones cover a large proportion of the surface. The glaciers during their advance over this area ground up vast quantities of the surface rocks, leaving the pulverized débris in the form of deposits of limey gravels and limey clays.

Surface waters running through such areas, or underground waters percolating through beds of limestone or coarse limey clays, will, if charged with carbon dioxide, dissolve and carry off lime carbonate, the exact amount so dissolved being determined by the percentage of CO_2 contained in the water, its temperature, etc. The tendency is for every water to charge itself with its maximum possible amount of calcium bicarbonate, and until it is so charged it will continue to attack and dissolve limestones which it encounters in its course.

When the water is almost or quite saturated with calcium bicarbonate, any increase in temperature or decrease in pressure will cause the deposition of lime carbonate. Reactions of this type have been appealed to as explanations of the formation of marl deposits through the warming or loss of pressure which occurs when spring or stream water enters a lake. A recent statement * of this theory is as follows:

"This spring-water as it enters the lake is always colder than the waters of the lake itself. The bicarbonate of lime is more soluble in cold water than in warm and a *part* of the dissolved material is therefore precipitated in the form of a fine powder soon after the cold stream enters the warmer, still water of the lake. Such precipitation of calcium carbonate from cold water as it becomes warm is seen every day in almost every household. The hard water heated in tea-kettles holds while cold a large quantity of bicarbonate of lime in solution. As it becomes warm, much, if not all, of this falls and forms a coating of lime carbonate upon the bottom of the kettle.

"Again, if there is a large amount of carbon dioxide in the percolating waters the percentage of carbonate of lime held in solution will be increased in proportion. As the spring-water enters the lake and rises to the surface the pressure will be decreased and a part of the carbon dioxide will escape and so cause a precipitation of *another* part of the carbonate of lime according to the following formula:

$$\text{“}CaH_2(CO_3)_2 - CO_2 = CaCO_3 + H_2O.\text{”}$$

In support of his belief that the formation of most marl deposits is due to the two causes above outlined, Blatchley urges that most, if not all, of the marl lakes examined in Indiana are fed by subterranean or subaqueous springs, even though they also have streams entering and leaving them, and that "the larger deposits of marl in the lakes are found in close proximity to these springs".

Davis, in studying the Michigan marls, came to the conclusion that the causes above noted would not of themselves account for the

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* Blatchley, W. S. 25th Ann. Rep. Indiana Dept. Geology, p. 45.

majority of marl deposits. His studies * led him to believe that more important effects were due to the action of certain aquatic plants of low type, notably *Chara* (sonewort) and *Zonotrichia*, another alga. Plants of higher type are also influential in marl deposition, but to a less degree. Davis has summarized † his views as follows:

"All green plants, whether aquatic or terrestrial, take in the gas (carbon dioxide) through their leaves and stems and build the carbon atoms and part of the oxygen atoms of which the gas is composed into the new compounds of their own tissues, in the process releasing the remainder of the oxygen atoms. Admitting these facts, we have two possible general causes for the formation of the incrustation (of calcium carbonate) upon all aquatic plants. If the calcium and other salts are in excess in the water, and are held in solution by free carbon dioxide, then the more or less complete abstraction of that gas from the water in direct contact with plants causes precipitation of the (lime) salts upon the parts abstracting the gas, namely, the stems and leaves. But in water containing the salts, especially calcium bicarbonate, in amounts so small that they would not be precipitated if there were no free carbon dioxide present in the water at all, the precipitation may be considered a purely chemical problem, a solution of which may be looked for in the action, upon the bicarbonates, of the oxygen set free by the plants. Of these bicarbonates, calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the following chemical equation:

$$\underset{\text{Calcium bicarbonate}}{CaH_2(CO_3)_2} + \underset{\text{oxygen}}{O} = \underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} + \underset{\text{oxygen}}{O},$$

in which the calcium bicarbonate is converted into the normal (and very slightly soluble) carbonate by the oxygen liberated by the plants, and both carbon dioxide and oxygen are set free, the free oxygen possibly acting still further to precipitate calcium monocarbonate. It is probable that the plants actually do precipitate calcium carbonate in both these ways (i.e., by abstracting carbon dioxide from the water and by freeing oxygen), but in water containing relatively small amounts of calcium bicarbonate the latter would seem to be the probable method."

Professor Davis has further proven that *Chara* acts in still a third way, abstracting lime salts directly from the water as part of its life processes and depositing them in its tissues.

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* See papers by Davis, cited in list on pp. 346–347.

† Vol. 8, pt. 3, Reports Michigan Geol. Survey, p. 69.

A further possible mode of derivation, which is admittedly the way in which *part* of all the marl deposits have originated, is through the direct action of molluscs. These animals are especially frequent in limey waters and have the power of abstracting lime salts from the water and utilizing the resulting lime carbonate in the formation of their shells. On the death of the animals their shells sink to the bottom and form an essential portion of any deposit which is in process of formation. In some marl-beds shells amount to an important percentage of the total, but in most cases they will probably constitute less than 5 per cent of the entire mass.

The facts so far stated may be summarized as follows: Spring or stream water, carrying lime carbonate in solution, deposits it in lakes in the form of marl, this deposition being caused by:

(*a*) Escape of carbon dioxide, owing to decrease in pressure;
(*b*) Supersaturation, owing to rise in temperature;
(*c*) Abstraction of carbon dioxide by plants;
(*d*) Freeing of oxygen by plants, resulting in formation of carbonates from bicarbonates;
(*e*) Direct abstraction and crystallization of lime salts by *Chara*.
(*f*) Abstraction of lime by molluscs and formation of shell deposits.

The formation of a given marl-bed may be due to the operation of any one of these causes, or the cooperation of two or more of them.

Geographic distribution of marl deposits.—The geographic distribution of marl deposits is intimately related to the geologic history of the region in which they occur. Marl-beds are, as indicated in the preceding section, the result of the filling of old lake basins. Lakes are not common except in those portions of the United States which were affected by glacial action, since lakes are in general due to the damming of streams by glacial material or to irregularities in deposition of such material. Workable marl deposits, therefore, are almost exclusively confined to those portions of the United States and Canada lying north of the former southern limit of the glaciers.

Marl-beds are found in the New England States, where, however, they are seldom of important size, and in New York, large beds occurring in the central and western portions of that State. Deposits are frequent and important in Michigan, and in the northern portions of Ohio, Indiana, and Illinois. Marl-beds occur in Iowa, Wisconsin, and Minnesota, but have not been as yet exploited for cement-manufacture. Extensive marl-beds also occur in Ontario, Quebec, and other Canadian provinces.

Physical characters of marl.—Marl as found in existing lakes may contain as high as 50 per cent of water, while even the dry marl-beds occurring in swamps or marshes will carry 15 to 25 per cent of moisture. This moisture, together with the fine granular character of the marl itself, gives it a sticky, putty-like character. In color pure marl is white, but it usually contains so much organic matter as to give even the better samples a grayish or yellowish tint, while the more impure marls may be very dark gray in color.

Marl usually contains very little sand or grit, though some of its shells and lime carbonate particles may give it a gritty feeling when examined. Such shells, etc., can, however, be usually crushed between the fingers, which will serve to distinguish them in the field from sand grains. Though as sticky as clay, marl is markedly lighter in weight, owing to the high percentage of moisture which it contains.

The natural fineness of marl is a matter which is of direct interest to the Portland-cement manufacturer, because of its effect on the cost of grinding the raw material. Marls differ quite widely in this regard, some being fine-grained throughout, while others contain considerable percentages of coarse material, including shells, etc.

The sieving tests tabulated below * were carried out by Prof. Davis on samples of marl from three Michigan localities, and serve to show the differences in fineness above noted.

TABLE 156.

FINENESS OF CRUDE MARL. (DAVIS.)

	1.	2.	3.
	Per Cent.	Per Cent.	Per Cent.
Residue on 20-mesh sieve.	32.25	31.52	0.36
" " 40- " "	6.06	14.48	3.53
" " 60- " "	7.58	12.76	6.51
" " 80- " "	2.90	2.56	3.34
" " 100- " "	4.81	6.74	6.44
Passing 100- " "	46.40	31.94	79.82

1. Cedar Lake.
2. Littlefield Lake.
3. Michigan P. C. Co., Coldwater.

The weight of the marl is also a matter of economic interest. A wet marl, as dredged from a lake bottom carrying from 50 to 60 per cent of water, may average about 2000 lbs. per cubic yard, so that a cubic yard of such material would contain only about 800 to 1000 lbs. dry marl. A dry marl taken from a well-drained marsh or swamp may run as

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* Vol. 8, pt. 3, Reports Michigan Geol. Survey, pp. 74–77.

low as 20 per cent of water. Such a marl would then weigh about 2600 lbs. per cubic yard, and a cubic yard would contain about a ton of pure marl.

In dealing with the wet marls a cement-plant may produce from one and a half to three barrels of cement from each cubic yard of marl, while a marsh marl might yield four barrels cement per cubic yard. In estimating the life of a lake marl deposit it will be safest to assume that each cubic yard of marl in place will produce only two barrels of cement.

Chemical composition of marl.—Marl itself, being a chemical deposit, is almost a pure carbonate of lime. During and after its deposition, however, foreign matter of various kinds is apt to get mixed in with the marl, the principal impurities thus introduced being fine sand, clayey matter, and organic material. Of these the most important, from the cement manufacturer's point of view, is the organic matter.

Sand is rarely present in sufficient amount to render the marl unserviceable, and of the 2 or 3 per cent of sand shown by most marls some is fine enough to pass a 150-mesh sieve and will therefore enter into combination in the kiln. The clay present in marls is principally objectionable because of its tendency to increase the percentage of magnesia and sulphur trioxide.

Organic matter burns out in the kiln and might therefore be regarded as a harmless impurity. But a high percentage of it in a marl is in reality very objectionable, both negatively, because it lowers the percentage of lime carbonate in the marl, and positively, because it retains moisture with great avidity. It is almost impossible to dry a marl containing much organic matter, and in any semi-dry or dry process this would be a very serious disadvantage. Organic matter in its coarser forms —i.e., roots, branches, twigs, etc., interferes greatly with the grinding of the marl, though the larger fragments are usually taken out by a separator early in the reducing process.

In the following table (157) are given the analyses of marls used at different American cement-plants, some quoted from published sources and others supplied by the chemists of the plants. A few of the quoted analyses are taken from prospectuses, but in general the analyses are of more satisfactory character. In all cases they are calculated dry, all water below 212° being neglected.

The analyses given in this table are mostly not picked analyses, such as are usually quoted in prospectuses, in which the marl rarely carries less than 98 per cent of lime carbonate. On the other hand, some of them are still considerably better than can be expected

TABLE 157.

ANALYSES OF MARLS USED IN AMERICAN CEMENT-PLANTS.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron Oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies (K_2O, Na_2O).	Sulphur Trioxide (SO_3).	Carbon Dioxide (CO_2).	Organic Matter.
1	1.74	0.90	0.28	49.84	1.75	....	1.12	46.01	
2	1.78	1.21		49.55	1.30	....	1.58	40.35	4.23
3	0.85	0.86		51.04	1.31	....	....		
4	0.66	0.62		53.17	0.47	....	....	42.35	2.53
5	3.80	n. d.		51.10	1.54	....	0.24	41.82	1.50
6	0.19	0.05	0.07	51.31	1.93	....	0.14	42.40	2.25
7	0.22	0.76		51.56	1.26	....	....	46.20	
8	0.77	0.11		53.58	0.91	....	....	43.14	
9	1.24	0.80		50.90	1.43	....	....	41.54	4.09
10	0.72	0.24	0.12	55.12	0.44	....	tr.	43.77	
11	0.06	0.80		55.00	....	....	0.05	43.22	
12	1.19	0.55	0.25	52.50	1.16	1.84	tr.	42.51	n. d.
13	1.20	0.55	0.40	51.15	0.37	5.79	0.26	40.59	n. d.
14	n. d.	n. d.	n. d.	51.90	0.83	n. d.	0.20	41.67	n. d.
15	1.65	0.81		50.77	tr.	n. d.	0.66	39.89	n. d.
16	0.4	0.2	0.2	53.50	0.3	....	1.7		
17	0.42	1.08		52.36	1.01	....	2.01	42.26	0.86
18	0.26	0.10		52.86	0.18	....	....	41.73	1.54
19	0.26	0.21	0.01	50.98	0.19	....	....	40.26	1.68
20	6.22	1.70	0.86	47.86	0.04	2.20	....	42.11	
21	0.14	0.36		53.16	1.50				
22	0.54	0.56		54.40	2.34	....	....	42.20	
23	1.98	0.97		50.95	0.55	0.12	0.10	40.03	0.25
24	0.26	0.20		52.86	n. d.				
25	1.43	0.20	0.18	50.62	2.09			45.58	
26	0.46	0.44		54.44	0.30	....	....	43.10	1.12

1–2. Sandusky P. C. Co., Syracuse, Ind. S. B. Newberry, analyst. 25th Ann. Rep. Indiana Dept. Geology, p. 29, 182.
3. Wabash P. C. Co., Stroh, Ind. W. R. Oglesby, analyst. 25th Ann. Rep. Indiana Dept. Geology, p. 112.
4. Wabash P. C. Co., Stroh, Ind.
5. Millens P. C. Works, South Bend, Ind. H. H. Hooper, analyst. 25th Ann. Rep. Indiana Dept. Geology, p. 25.
6. Millens P. C. Works, South Bend, Ind. W. A. Noyes, anaylst. 25th Ann. Rep. Indiana Dept. Geology, p. 273.
7. Peninsular P. C. Co., Cement City, Mich. J. G. Dean, analyst. Vol. 8, Mich. Geol. Survey, p. 236.
8. Newaygo P. C. Co, Newaygo, Mich. Lathbury and Spackman, analysts. Manufacturer's prospectus.
9. Newaygo P. C. Co., Newaygo, Mich. Vol. 8, Mich. Geol. Survey, p. 240.
10. " " " " Allerman, analyst. Manufacturer's prospectus.
11. " " " " " "
12–13. Wolverine P. C. Co., Coldwater, Mich. H. E. Brown, analyst. Vol. 8, Mich. Geol. Survey, p. 247.
14. Wolverine P. C. Co., Coldwater, Mich. "Cement Industry", p. 78.
15. Bronson P. C. Co., Bronson, Mich. Mineral Industry, vol. 6, p. 99.
16. Iroquois P. C. Co., Caledonia, N. Y. 22d Ann. Rep. N. Y. State Geologist.
17. Millens P. C. Works, Wayland, N. Y.
18–19. Empire P. C. Co., Warners, N. Y.
20. Montezuma, N. Y. First marl used for cement. Mineral Industry, vol. 1, p. 52.
21. American C. Co., Jordan, N. Y.
22. Genesee Wayland P. C. Co., Perkinsville, N. Y.
23. Buckeye P. C. Co., Harper, Ohio. Mineral Industry, vol. 1, p. 52.
24. Castalia P. C. Co., Castalia, Ohio.
25. Imperial P. C. Co., Owen Sound, Ontario.
26. Canadian P. C. Co., Marlbank, Ontario. Rep. Ontario Bureau Mines, 1901, p. 16.

in steady practice. The following data may throw some light on what sort of results are really obtained when a marl deposit is worked continuously.

First, as to water percentages: At a Michigan plant which takes its marl from under about 10 feet of water, an average of ten consecutive analyses gave the following results.

Silica (SiO_2)	0.07	
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	} 0.18	
Lime carbonate ($CaCO_3$)	39.80	(=CaO 22.29%)
Organic matter	0.59	
Water	59.36	

The marl in question is, it will be noted, very pure, being low in both clay and organic matter. The point to be noted is the high percentage of water, each 100 lbs. of material dredged containing approximately only 40 lbs. of lime carbonate, with 60 lbs. of water. It must be borne in mind that this marl was not pumped to the plant, so that this large percentage of water represents only what was unavoidably taken up with the marl during dredging.

Second, as to purity: A long series of analyses of marl at another prominent Michigan plant gave the following limits of results. These are calculated on a *dry* basis, the 55 per cent or so of water which the marl carried when reaching the plant being neglected.

Silica (SiO_2)	1.40	to	8.60
Alumina (Al_2O_3)	0.55	"	1.30
Iron oxide (Fe_2O_3)	0.25	"	1.54
Lime (CaO)	54.60	"	46.20
Magnesia (MgO)	1.25	"	2.78
Carbon dioxide (CO_2)	42.90	"	36.30
Organic matter	0.05	"	10.50

It will be seen from these results that the manager should expect to receive material carrying often very high percentages of water and frequently containing a large amount of organic matter and other impurities.

Examining marl deposits.—Owing to the nature of the material and the physical conditions under which it occurs, the work of examining and valuing a marl deposit presents certain features of difficulty peculiar to itself. As in any other prospecting work, the two factors which require determination are respectively the extent of the deposit and the composition of the material.

When the marl occurs in an old lake-bed overlain by soil or peat, the area can be roughly laid out into blocks or squares of convenient size, borings being made and samples taken at the corners of these squares. A pocket compass, or, better yet, the cheap "drainage level" made by Gurley and other instrument-makers, will suffice for laying out the work.

A marl deposit covered by water must be handled like any sounding proposition. The shore line should first be roughly surveyed, after which soundings and borings must be made from a raft or boat, the position of each boring being located by bearings taken to fixed points in the shore. A broad steady platform is necessary for the borings. This is afforded either by using a raft with a square opening in its center or by laying planks across the ends of two boats.

As the methods employed in determining the thickness and character of marl-beds are of a somewhat special character and are not fully described in current engineering text-books, the writer feels justified in introducing here a very detailed account of these methods by Mr. David J. Hale, of the Michigan Geological Survey. This account is taken almost verbatim from the paper cited below.*

In dealing with fairly solid marls not deeply covered with peat or soil, the simple outfit described below has proven very successful when manipulated with care. It is prepared as follows:

Weld an ordinary 2-inch auger on a $\frac{3}{8}$-inch gas-pipe 2 feet long. Thread the unwelded end of the pipe for coupling. Cut three lengths of pipe each in half or in four pieces if it is desired to carry the outfit long distances. Thread the ends of these sections for coupling. Get couplings enough to couple all together, so as to make a continuous hollow rod with attached auger. Insert a "T" coupling on the handle end, or end farthest from the auger, and pass a rod or stick through this so as to turn the outfit. A better way is to screw into each free end of the "T" a rod or piece of gas-pipe 18 inches long. Usually a pair of Stillson wrenches are needed to untwist the pipe, which becomes jammed during the boring.

Three-eighths-inch pipe, as above recommended, will be found to lift out much easier than half-inch, but will not do for deep boring; $\frac{3}{16}$-inch pipe is entirely too light and 1-inch pipe is too difficult to handle. A light, easily handled outfit is a great aid in boring, because the quicker the rod can be driven the less friction there will be to contend with, for the marl particles will not have time to settle after each movement of the rod.

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* Hale, D. J. The use of marl for cement manufacture. Vol. 8, pt. 3, Reports Mich. Geol. Survey, especially pp. 9–13, 108–110.

In boring, the handle should be twisted around as the rod is shoved down, even though the surface material may be soft enough to permit it to be driven down without twisting, because if the latter method is adopted the surface material first taken up by the auger will cling to it during its descent, and will prevent securing a sample of the marl at lower depth. As each new length of pipe is added, the couplings should be firmly tightened, as neglect of this precaution may mean the loss of most of the outfit through uncoupling while it is being drawn up.

This device gives good results when employed on a fairly dense marl not deeply covered by peat or grass, because the auger will clear itself of the surface material on the way down and will retain fairly well the clean sample taken at the bottom.

In heavily covered marl-beds, or in dealing with very fluid marls, other boring devices must be tried. A clumsy but efficient type of sampler for this purpose is made as follows: Take a 2-foot length of 1-inch gas-pipe and thread one end for coupling. Screw reducers on the coupled end until the last reducer can take a $\frac{3}{8}$-inch or $\frac{1}{2}$-inch pipe, any necessary number of lengths of which pipe will form the rod proper. Sharpen the open edge of the 1-inch pipe and fit into it a plug with a shoulder that fits against the rim, allowing the plug to penetrate $\frac{1}{2}$ inch into the open end of the pipe. Sharpen the end of the plug opposite the shoulder and bore a hole lengthwise through the plug. Pass a $\frac{3}{16}$-inch iron rod through the plug from the shoulder end and bolt it by screwing a nut upon the end opposite the shoulder, which end should be sharpened so as to penetrate the marl more easily. The end of the rod may be threaded for several inches and a nut screwed on, then pass the end of the rod through the plug and screw the nut tight against the plug. This will hold the plug in place during boring and withdrawing. The rod is inserted in the 1-inch pipe and passed up through that and the $\frac{3}{8}$-inch pipe, from the upper end of which the free end of the rod may project. The rod gives a means of either closing firmly or opening the bottom end of the 1-inch pipe. When boring, the plug is held firmly against the mouth of the pipe by means of the rod, and the whole apparatus is shoved down into the marl to the desired depth. The pipe is then raised, while the rod is held stationary; the apparatus is held in this position a moment to allow the marl to close in about the rod and then the pipe is lowered until the plug closes it. With the plug held firmly the entire apparatus is raised to the surface, the plug loosened, and the sample of marl taken out of the section of 1-inch pipe. This device can be driven through and withdrawn from a marl-bed covered by peat, grass, etc., and still the marl sample can be preserved from intermixture with these materials.

A borer invented and manufactured by Robert G. Hunt & Co. is also noted by Mr. Hale. This consists of a piece of steel about 18 feet long, much the shape of the half of a long gun-barrel split longitudinally. The end which first enters the marl is capped and pointed with steel so that it will penetrate more easily, while the other end is provided with a handle for raising the apparatus. The two vertical edges of the barrel are sharpened so as to cut the marl. When the instrument has been driven down to the desired depth it is turned half around, filling the half cylinder with marl for its entire length, and then withdrawn. This gives a perfect sample of the bed from top to bottom.

The various devices above described will generally give satisfactory results when operating in moderate depths of water and on any but the most fluid marls. For these latter, as well as for sampling in deep water, special devices are required, which are described by Mr. Hale in the paper cited. But in examing deposits of marl to be used as Portland-cement material the very deep and very fluid marls may be dismissed without sampling. For under present economic conditions such materials could not be profitably used in cement-manufacture.

After the results of the borings have been plotted in such a way as to give both depth of water and thickness of marl, the amount of marl available can be calculated quite closely. In making these estimates it will be safest to assume that each cubic yard of marl in the lake will yield 900 pounds of *dry* marl, or sufficient to make two barrels of cement. Each rotary kiln in the prepared plant will on this basis use about 50 to 60 cubic yards of marl per day, or about 18,000 cubic yards per year. An eight-kiln plant should therefore own about 3,000,000 cubic yards of marl, which would insure a twenty-year supply of raw material.

List of references on marls.—Of the following papers on marls, those dealing chiefly with the origin of marl deposits are marked *A*; those describing the deposits of certain States or areas are marked *B*; and those discussing the technology of marls as cement materials are marked *C*:

A, B. Blatchley, W. S., and Ashley, G. H. The lakes of northern Indiana and their associated marl deposits. 25th Ann. Rep. Indiana Dept. Geology and Natural Resources, pp. 31–321. 1901.

A. Davis, C. A. A contribution to the natural history of marl. Journal of Geology, vol. 8, pp. 485–497. 1900.

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CHAPTER XXVI.

ALKALI WASTE: BLAST-FURNACE SLAG.

THE two raw materials to be discussed in the present chapter agree in being waste products or by-products of other industries which, because of their chemical composition, can be used in Portland-cement manufacture. In almost every other respect they differ. Alkali waste is a fine-grained, soft and pure form of lime carbonate. Slag is very hard, coarse-grained, and is composed of lime (CaO), silica, and alumina.

Waste products or by-products can, of course, be usually obtained at a low or nominal cost, and on this account both slag and alkali waste assume an importance entirely out of proportion to their other properties. But it must be recollected that as by-products their production and quality depend entirely upon the condition of the industries of which they are wastes, and that no furnace manager or alkali-works superintendent will run his plant solely in order to turn out a by-product regular in amount and composition. For this reason it is essential that a cement-plant using a waste product must be closely identified in ownership with the furnace or works which furnishes this waste product. Common ownership is practically the only way of insuring a sufficient and regular supply of satisfactory composition.

Alkali Waste.

A large amount of waste material results from the processes used at alkali works in the manufacture of caustic soda. This waste material is largely a precipitated form of calcium carbonate, and if sufficiently free from injurious impurities, furnishes a cheap source of lime for use in Portland-cement manufacture. The value of the waste for this purpose depends largely on the process from which it resulted.

Leblanc-process waste.— The waste resulting from the Leblanc process carries a very large percentage of sulphur, mostly in the form of lime sulphides, carried over from the pyrites used in the process. A fairly typical analysis * of Leblanc-process waste is given below and will serve to show the composition of this material:

Lime carbonate ($CaCO_3$)	41.20
Lime sulphate ($CaSO_4$)	2.53
Lime hydrate (CaH_2O_2)	8.72
Lime disulphide (CaS_2)	5.97
Lime sulphide (CaS)	25.79
Sodium sulphide (Na_2S)	1.44
Magnesium silicate ($MgSiO_3$)	3.63
Phosphates of iron and alumina	8.91

This material is obviously unfit for use in the manufacture of Portland cement. Attempts have been made to recover the sulphur contained in the waste, but the removal of this constituent is never sufficiently perfect to permit the resulting waste to be of use to the cement manufacturer.

Ammonia-process waste.—The waste from ammonia-process works is, on the contrary, a very pure mass of precipitated lime, mostly in the carbonate form, though some lime hydrate is always present. As pyrite is not used in this process, the sulphur in the waste is commonly well within Portland-cement limits. The magnesia content of the waste may or may not be high, according to the character of the limestone that has been used in the process of soda-manufacture. When a pure limestone low in magnesium carbonate has been used, the waste will be low in magnesia and is then a very satisfactory Portland-cement material. The following analyses are representative of the waste obtained at alkali-plants using the ammonia process.

TABLE 158.

ANALYSES OF ALKALI WASTE, AMMONIA PROCESS.

	1.	2.	3.	4.	5.
Silica (SiO_2)	0.60	1.98	1.75	n. d.	0.98
Alumina (Al_2O_3)	3.04	1.41	0.61	2.20	1.62
Iron oxide (Fe_2O_3)		1.38			
Lime (CaO)	53.33	48.29	50.60	52.40	50.40
Magnesia (MgO)	0.48	1.51	5.35	3.75	4.97
Alkalies (K_2O,Na_2O)	0.20	0.64	0.64	0.20	0.50
Sulphur trioxide (SO_3)	n. d.	1.26	n. d.	n. d.	n. d.
Sulphur (S)	n. d.	n. d.	0.10	n. d.	0.06
Carbon dioxide (CO_2)	42.43	39.60	41.70	41.17	n. d.
Water	n. d.	3.80		n. d.	n. d.

The analyses given in the above table are of alkali wastes which have at one time or another been used in the manufacture of Portland

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* Kingzett, C. T. The Alkali Trade, p. 134.

cement either in the United States or in England. The effect on the waste when a magnesian limestone is used in the alkali-plant is well shown by analyses 3, 4 and 5, in all of which the magnesia is high for a Portland-cement material.

At the only American cement-plant which uses alkali waste the materials (clay and waste) are mixed wet. The waste carries 90 to 95 per cent of lime carbonate, while the clay used gives the following analysis:

Silica (SiO_2)	63.54
Alumina (Al_2O_3)	24.00
Iron oxide (Fe_2O_3)	
Lime (CaO)	1.66
Magnesia (MgO)	1.05
Alkalies (K_2O,Na_2O)	0.78
Carbon dioxide (CO_2)	2.47
Water	7.05

The clay is put through a rotary drier and ground in a dry-pan, after which the waste and clay are mixed in a wet pug-mill and ground in wet tube mills. The mix is made drier than at most of the plants using marl and contains usually about 40 per cent of water.

It is not, of course, necessary that wet mixing should be practiced when alkali waste is employed as one raw material. The waste could be dried, though it is possible that its physical properties might render this more difficult than drying limestones or clays.

List of references on alkali waste as a cement material.—The following brief list covers the few available references on this subject:

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Lathbury, B. B. The Michigan Alkali Company's plant for manufacturing Portland cement from caustic-soda waste. Engineering News, June 7, 1900.

Lathbury, B. B., and Spackman, H. S. The Michigan Alkali Company's plant, Wyandotte, Michigan. The Rotary Kiln, pp. 110–119. 1902.

Redgrave, G. R. [Use of alkali waste in England.] Calcareous Cements: their Nature and Uses, pp. 182–184. 1895.

Blast-furnace Slag.

True Portland cements, which must be sharply distinguished from the slag (or puzzolan) cements described in Part VII of this volume, can be made from mixtures which contain blast-furnace slag as one ingredient. In this case the slag is intimately mixed with limestone and the mixture is finely powdered. It is then burned in kilns and the resulting clinker pulverized.

The slags from iron furnaces consist essentially of lime (CaO), silica (SiO_2), and alumina (Al_2O_3), though small percentages of iron oxide (FeO), magnesia (MgO), and sulphur (S) are commonly present. Slag may therefore be regarded as a very impure limestone or a very calcareous clay from which the carbon dioxide has been driven off.

Two plants are at present engaged in the United States in the manufacture of true Portland cement from slag, and there seems to be no reason why this cheap and satisfactory raw material should not become an important factor in the cement industry of the country.

Slags in general.—Slags are the fusible silicates formed, during the smelting or refining of metals, by the combination of the fluxing materials with the gangue of the ore. The composition of the slag, therefore, will be determined by the composition and relative proportions of the fluxes and the gangue. In general, the slag will contain only those elements which are present in either the gangue or the flux, though it may carry also a percentage, usually small, of the metal which is being smelted or treated. In some processes also the composition of the slag may be slightly modified through the action of the fuel, from which certain impurities may be taken up.

While many elements may occur in slags, those which are of universal or even common occurrence are comparatively few. The slags commonly found in iron metallurgy consist essentially of silica, alumina, iron oxide, and lime, with or without magnesia. Alkalies, sulphur, and phosphorus are also almost invariably present, but in small percentages.

The following analyses of slags from various furnaces will serve to give some idea of the range in composition of these products.

TABLE 159.

ANALYSES OF IRON-FURNACE SLAGS.

Silica (SiO_2)	30.00	30.72	32.51	32.90	26.88	31.65
Alumina (Al_2O_3)	28.00	16.40	13.91	13.25	24.12	17.00
Iron oxides (FeO, Fe_2O_3)	0.75	0.43	0.48	0.46	0.44	0.65
Lime (CaO)	32.75	48.59	44.75	47.30	45.11	47.20
Magnesia (MgO)	5.25	1.28	2.20	1.37	1.09	1.36
Lime sulphide (CaS)	1.90	2.16	4.90	3.42	1.86	n. d.

Silica (SiO_2)	28.35	38.00	31.50	32.20	33.10
Alumina (Al_2O_3)	18.15	10.00	18.56	15.50	12.60
Iron oxides (FeO, Fe_2O_3)	1.50	n. d.	n. d.	n. d.	n. d.
Lime (CaO)	47.40	46.0	42.22	48.14	49.98
Magnesia (MgO)	2.45	n. d.	3.18	2.27	2.45
Lime sulphide (CaS)	n. d.	n. d.	n. d.	n. d.	n. d.

Slags used as Portland-cement materials.—The slags used in Portland-cement manufacture are iron blast-furnace slags of the more basic types—i.e., those in which the lime (CaO) reaches 30 per cent or over. The higher the lime, up to say 50 per cent, the more valuable the slag for this use. The composition of the slags will usually be controlled, however, by the requirements of the furnaces, not by the needs of the cement-plant.

The following shows the range in composition of the slags used at a German Portland-cement plant.

ANALYSES OF SLAG USED IN PORTLAND-CEMENT MANUFACTURE.

	Per Cent.
Silica (SiO_2)	30 to 35
Alumina (Al_2O_3)	10 " 14
Iron oxide (FeO)	0.2 " 1.2
Lime (CaO)	46 " 49
Magnesia (MgO)	0.5 " 3.5
Sulphur trioxide (SO_3)	0.2 " 0.6

As a Portland-cement material slag possesses one great advantage in addition to its cheapness. This advantage is chemical, and is due to the fact that the lime contained in the slag is present in the form of oxide (CaO), instead of carbonate ($CaCO_3$), as in limestones. It does not require to be decarbonated, and therefore a mixture made up of slag and clay will clinker with less fuel than one consisting of limestone and clay.

Opposed to this chemical advantage is a physical disadvantage. If the slag is allowed to cool as it issues from the furnaces, it solidifies into very hard and tough masses much more resistant than the hardest of limestones. In order to avoid this difficulty, it is the common practice to "granulate" the slag, i.e. to run it direct from the furnace into cold water. This proceeding breaks up the slag into little porous granules $\frac{1}{10}$ to $\frac{1}{2}$ inch in diameter, and incidentally removes part of the sulphur contained in the slag. But to offset these gains, it introduces a large amount of water into the product, so that a granulated slag may carry from 20 to 40 per cent of water, and this greatly increases the cost of drying.

As the chemical and physical properties of slag introduce certain interesting features into the manufacture of Portland cement from a limestone-slag mixture, this mixture will be discussed separately on later pages.

CHAPTER XXVII.

CLAYS, SHALES, AND SLATES.

Except when a very clayey limestone or a slag is one component of a Portland-cement mixture, the silica, alumina and iron oxide necessary for the mix are always supplied in the form of clay, shale, or slate.

The materials known respectively as clays, shales, and slates are of practically the same composition and ultimate origin, but differ in their degree of consolidation.

Clays are ultimately derived from the decay of older rocks, the finer particles resulting from this decay being carried off and deposited by streams along their channels, in lakes, or along parts of the seacoast or sea-bottom as beds of clay. In chemical composition the clays are composed essentially of silica and alumina, though iron oxide is almost invariably present in more or less amount, while lime, magnesia, alkalies, and sulphur are of frequent occurrence, though usually only in small percentages.

Shales are clays which have become hardened by pressure. The so-called "fire-clays" of the Coal Measures are shales, as are many of the other "clays" of commerce. The slates include those clayey rocks which through pressure have gained the property of splitting readily into thin parallel leaves.

Clays.—The term clay is applied to fine-grained unconsolidated materials which possess the property of plasticity when wet, while they lose this property and harden on being strongly heated. Being, as explained below, the finer débris resulting from the decay of many different kinds of rocks, the clays will naturally differ greatly among themselves in composition, etc.

Origin of clays.—When rocks of any kind are exposed to atmospheric action, more or less rapid disintegration sets in. This is due partly to chemical and partly to physical causes. It is hastened, for example, by the dissolving out of any soluble minerals that may occur in the rock, by the expansion and contraction due to freezing, and by the action of the organic acids set free by decaying vegetable matter. The more soluble ingredients of the rock are usually removed in solution by surface or percolating waters, while the more insoluble portions are either left behind or are carried off mechanically by streams. These relatively insoluble materials when sufficiently fine grained constitute the clays. When they are left as a deposit in the spot where the original rock disintegrated, they are called *residual* clays; when they are carried off by surface-waters and finally deposited in the sea or along river-beds they are *transported* or *sedimentary* clays. A third class of particular interest to the cement manufacturer are the *glacial* clays, deposited under or in front of the glaciers which formerly covered most of the northern states.

Composition of clays.—The residual, sedimentary and glacial clays usually differ markedly in composition, owing to the different manner in which they have been deposited. The residual clays, for example, are apt to contain coarse fragments of any very insoluble and hard material which the original rock may have contained. A residual clay arising from the decay of a granite will probably contain fragments of quartz; one derived from a limestone may contain chert or flint, as well as masses of undissolved lime carbonate. A sedimentary clay, on the other hand, having been transported by water for great distances, has usually lost all its coarser material, and is a fine grained and homogeneous product. The glacial clays, being formed mechanically by the abrading power of the ice, show even less homogeneity than the residual clays, and are apt to contain much sand, gravel, and pebbles.

Clays used in Portland-cement manufacture.—For use as Portland-cement materials clays should be as free as possible from gravel and sand, as the silica present as pebbles or grit is practically inert in the kiln unless ground more finely than is economically practicable. In composition they should not carry less than 55 per cent of silica, and preferably from 60 to 70 per cent. The alumina and iron oxide together should not amount to more than one-half the percentage of silica, and the composition will usually be better the nearer the ratio $Al_2O_3+Fe_2O_3=\frac{SiO_2}{3}$ is approached.

Nodules of lime carbonate, gypsum, or pyrite, if present in any quantity, are undesirable; though the lime carbonate is not absolutely injurious. Magnesia and alkalies should be low, preferably not above 3 per cent.

The clays actually used in cement plants may be separated, for convenience, into the *normal* clays and the *limey* clays. In this section the dividing line between these classes will be fixed arbitrarily at 5 per cent of lime (CaO) and magnesia (MgO) together, all clays containing over 5 per cent of both oxides being called limey clays, while those carrying less than 5 per cent are termed normal clays.

TABLE 160.

ANALYSES OF NORMAL CLAYS USED IN AMERICAN CEMENT-PLANTS.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron Oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies (K_2O,Na_2O).	Sulphur Trioxide (SO_3).	Carbon Dioxide (CO_2).	Water.	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
1	53.30	23.29	9.52	0.36	1.49	n. d.	n. d.	n. d.	n. d.	1.62
2	65.12	19.05	7.66	0.34	0.31	n. d.	n. d.	n. d.	n. d.	2.44
3	63.73	22.12	9.01	2.83	....	0.21	n, d.	n. d.	n. d.	2.04
4	53.21	15.91	7.25	1.89	0.99	2.21	0.97	17.21		2.29
5	59.10	25.41		3.61	0.87	1.10	0.31	9.81		2.32
6	58.02	26.12		3.70	1.00	1.55	0.33	9.27		2.22
7	57.25	26.15		3.09	1.10	1.88	0.39	9.30		2.19
8	58.25	18.56	7.35	3.10	1.28	2.35	0.45	8.55		2.25
9	74.29	12.06	4.92	0.41	0.68	2.56	n. d.	n. d.	n. d.	4.39
10	63.54	24.00		1.66	1.05	0.78	....	2.47	7.05	2.65
11	64.65	24.31		1.16	1.92	n. d.	n. d.	n. d.	n. d.	2.66
12	60.28	27.10		1.26	n. d.	n. d.	n. d.	8.38		2.22
13	60.30	29.78		1.98	n. d.	n. d.	n. d.	8.30		2.03
14	61.40	25.08		1.40	n. d.	n. d.	n. d.	6.60		2.45
15	63.82	25.36		3.42	n. d.	n. d.	n. d.	6.96		2.52
16	63.07	24.00		3.00	1.20	n. d.	n. d.	8.80		2.63
17	61.92	16.58	7.84	2.01	1.58	3.64	tr.	n. d.	n. d.	2.53
18	65.68	24.08		2.01	1.75	n. d.	n. d.	n. d.	n. d.	2.73
19	62.5	20.2	7.5	0.8	1.8	n. d.	0.4	n. d.	n. d.	2.26
20	58.90	27.50		4.08	0.79	n. d.	n. d.	n. d.	n. d.	2.14
21	59.10	24.01		2.20	2.00	n. d.	n. d.	n. d.	n. d.	2.46
22	64.85	17.98	5.92	2.24	1.40	n. d.	n. d.	4.98		2.82
23	58.04	14.63	9.27	1.53	2.02	n. d.	0.37	12.07		2.33

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TABLE 161.

ANALYSES OF LIMEY CLAYS USED IN AMERICAN CEMENT-PLANTS.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron Oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies (K_2O,Na_2O).	Sulphur Trioxide (SO_3).	Carbon Dioxide (CO_2).	Water.	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$.
1	47.5	33.0		4.0	2.0	1.5	n. d.	13.5		1.44
2	61.70	18.00		8.40	2.91	n. d.	n. d.	13.30		3.43
3	57.74	17.76		7.80	3.52	n. d.	n. d.	12.30		3.25
4	56.74	19.43	4.83	7.27	3.05	n. d.	n. d.	10.39		2.34
5	55.27	10.20	3.40	9.12	5.73	n. d.	n. d.	n. d.	n. d.	4.06
6	40.56	8.52	2.84	20.94	1.32	1.97	n. d.	17.90	5.95	3.57
7	59.36	10.01		23.80	2.40	0.58	1.71	....	2.05	5.93
8	58.05	25.50		2.50	3.24	n. d.	n. d.	8.80		2.27
9	46.40	16.30		14.20	2.06	0.75	n. d.	23.40	7.00	2.85
10	46.81	14.21		14.04	3.61	3.04	1.18	15.75	n. d.	3.29
11	55.84	8.90	3.02	9.98	5.16	n. d.	n. d.	13.68		4.69
12	55.27	28.15		5.84	2.25	n. d.	0.12	n. d.	n. d.	1.96
13	45.21	19.08	6.74	11.17	1.57	n. d.	1.55*	10.47	4.17	1.75
14	50.08	14.50	4.61	6.62	4.40	5.10	n. d.	n. d.	n. d.	2.62
15	40.48	20.95		14.45	0.47	3.14	n. d.	11.87	8.50	1.93
16	42.85	13.51	4.49	12.69	3.32	3.08	2.85	13.57	n. d.	2.38
17	53.50	24.20		5.15	2.15	n. d.	n. d.	14.10		2.21
18	52.00	31.00		7.10	3.33	n. d.	n. d.	n. d.	n. d.	1.68
19	52.10	35.56		5.90	3.33	n. d.	n. d.	n. d.	n. d.	1.46
20	51.56	14.50	3.84	9.80	n. d.	n. d.	tr.	7.70	n. d.	2.81
21	47.45	19.85		17.80	0.09	4.34	1.03	n. d.	n. d.	2.39
22	60.16	28.58		1.97	6.56	n. d.	n. d.	n. d.	n. d.	2.10
23	59.18	27.74		1.89	8.65	n. d.	n. d.	n. d.	n. d.	2.13
24	54.96	23.09	5.03	14.57	1.37	0.48	0.57	n. d.	n. d.	1.95
25	41.69	14.86	6.71	12.80	4.96	2.24	n. d.	16.74		1.93
26	39.23	12.13	2.79	21.61	2.69	1.69	n. d.	19.84		2.63
27	53.32	24.22		7.17	2.05	n. d.	n. d.	7.85	n. d.	2.20

* $CaSO_4$.

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19. " " " " " " " "
20. Castalia P. C. Co., Castalia, Ohio.
21. Buckeye, P. C. Co., Harper, Ohio. Mineral Industry, vol. 1, p. 52.
22. Clay used for reducer at a plant in the Lehigh district, Pa.
23. " " " " " " " " " " "
24. Orangeville, Ontario, Canada. Report Ontario Bureau of Mines, 1901.
25. Imperial P. C. Co., Owen Sound, Ontario, Canada.
26. " " " " " "
27. Canadian P. C. Co., Marlbrook, Ontario, Canada.

Shales.

It has been noted above that shales are simply clays which have been hardened by pressure. This statement, while approximately correct, requires some restriction. For the shales were formed almost entirely from extensive deposits of clays of marine origin, and, therefore, do not show the same irregularities of composition, etc., that modern clays exhibit. Shales, for example, rarely are so full of coarse sand and gravel as the glacial clays of Michigan and other Northern States.

TABLE 162.

ANALYSES OF NORMAL SHALES USED IN AMERICAN CEMENT-PLANTS.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron Oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Alkalies (K_2O,Na_2O).	Sulphur Trioxide (SO_3).	Carbon Dioxide (CO_2).	Water.	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
1	57.98	18.26	4.57	1.75	1.83	n. d.	1.28	12.08		
2	65.99	21.57	6.07	0.47	0.82	n. d.	n. d.	n. d.	n. d.	
3	63.30	26.00		1.25	1.25	n. d.	n. d.	n. d.	6.25	
4	63.56	27.32		1.20	1.20	n. d.	n. d.	n. d.	n. d.	
5	55.80	30.20		1.16	n. d.	n. d.	n. d.	n. d.	n. d.	
6	56.30	29.86		n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	
7	60.00	23.26	4.32	0.90	1.12	n. d.	n. d.	6.16		
8	62.67	19.99	5.46	1.25	0.72	n. d.	n. d.	n. d.	n. d.	
9	60.15	19.78	9.10	0.52	0.10	n. d.	tr.	n. d.	n. d.	
10	60.97	20.66	6.59	0.65	1.13	n. d.	tr.	n. d.	n. d.	
11	55.00	21.79	9.26	n. d.	n. d.	n. d.	n. d.	8.61		
12	54.70	31.68		1.15	n. d.	n. d.	n. d.	n. d.	n. d.	1.72
13	64.30	33.60		1.46	1.30	n. d.	n. d.	n. d.	n. d.	1.91
14	70.20	26.90		n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	2.61
15	61.09	19.19	6.78	2.51	0.65	3.16	1.42	5.13		
16	61.15	18.47	5.05	0.98	2.26	n. d.	0.91	7.02		
17	58.24	18.56	7.68	0.61	0.24	n. d.	n. d.	10.04		
18	59.64	19.14	7.59	0.26	2.31	4.33	n. d.	4.71		
19	62.10	20.09	7.81	0.65	0.96	n. d.	0.49			
20	59.02	29.84		0.68	2.16	n. d.	n. d.	n. d.	n. d.	
21	58.44	27.45		1.16	2.23	n. d.	n. d.	n. d.	n. d.	
22	58.90	27.25		1.23	2.18	n. d.	n. d.	n. d.	n. d.	
23	58.92	27.00		1.41	2.32	n. d.	n. d.	n. d.	n. d.	
24	60.24	30.04		2.21	1.55	n. d.	n. d.	n. d.	n. d.	2.01
25	60.02	26.60		2.31	1.62	n. d.	n. d.	n. d.	n. d.	

1. Western P. C. Co., Yankton, S. D. Mineral Industry, vol. 6, p. 97.
2. Crescent P. C. Co., Wampum, Pa.
3. Wellston P. C. Co., Wellston, Ohio. W. S. Trueblood, analyst.
4–7. Ironton P. C. Co., Ironton, Ohio. C. D. Quick, analyst.
8–11. Diamond P. C. Co., Middle Branch, Ohio. E. Davidson, analyst.
12–14. Hudson P. C. Co., Hudson, N. Y. Heiberg and Roney, analysts.
15. Alpena P. C. Co., Alpena, Mich. Vol. 8, pt. 3, Reports Mich. Geol. Survey, p. 227.
16. Wolverine P. C. Co., Coldwater, Mich.
17. Michigan P. C. Co., Coldwater, Mich. Cement Industry, p. 78.
18. Lehigh P. C. Co., Mitchell, Ind. 26th Ann. Rep. Indiana Dept. Geology, p. 276.
19. Bronson P. C. Co., Bronson, Mich. Mineral Industry, vol. 6, p. 99.
20. Peerless P. C. Co., Union City, Mich. Lundteigen, analyst.
22–25. Cayuga P. C. Co., Portland Point, N. Y. J. H. McGuire, analyst.

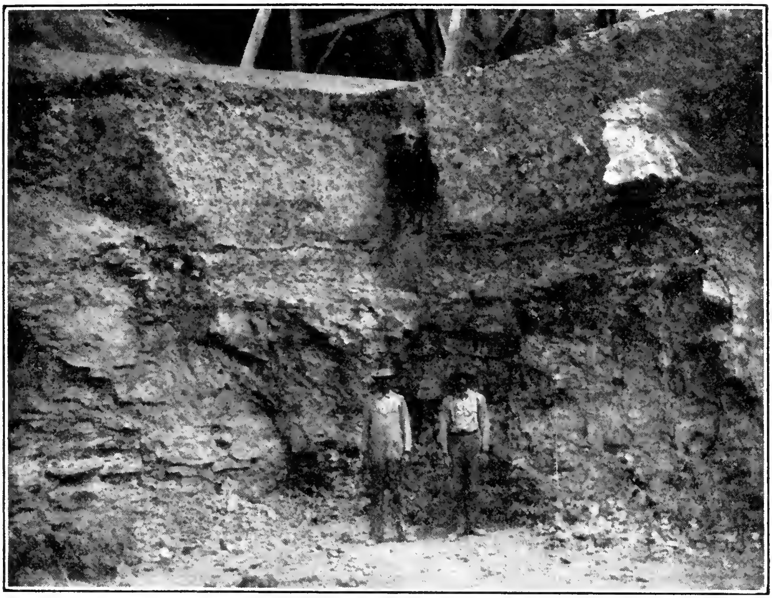

FIG. 69.—Pit in heavy shale-bed.

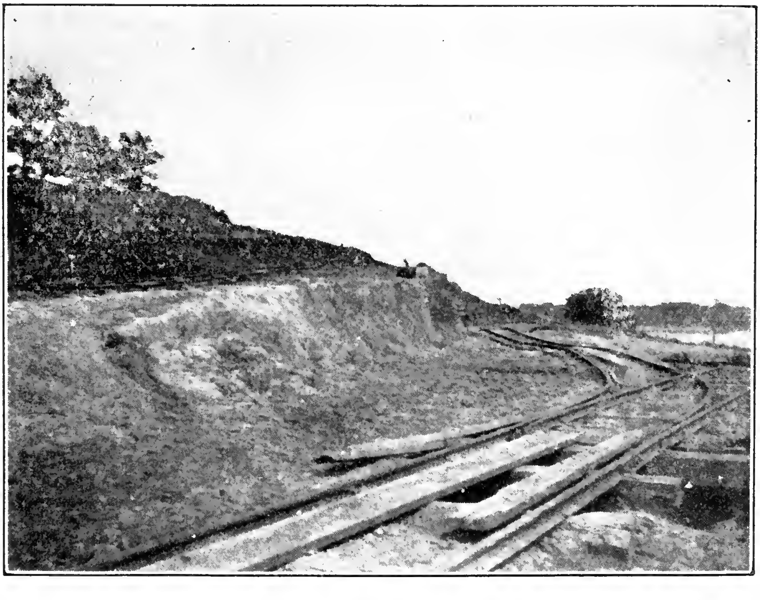

FIG. 70.—Shale-pit worked on two levels.

The limey shales are almost exclusively shales which occur interbedded, in comparatively thin layers, with limestones. Occasionally a limey shale will owe its content of lime almost entirely to the fossil shells it contains, the remainder of the shale being practically free from carbonates. For both of the above reasons limey shales are apt to be a source of trouble in the practical working of a plant and require considerable care in quarry management to insure that the raw materials are anywhere near uniform in composition from day to day.

Fig. 70 shows a shale deposit which consists of three horizontal

TABLE 163.

ANALYSES OF LIMEY SHALES USED IN AMERICAN CEMENT-PLANTS.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron Oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphur Trioxide (SO_3).	Carbon Dioxide (CO_2).	Water.	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$.
1	53.12	20.60	4.09	4.02	2.24	n. d.	13.70		2.15
2	54.30	19.33	5.57	3.29	2.57	2.36	n. d.	n. d.	
3	52.74	21.73		12.37	2.01	n. d.	11.27	n. d.	
4	54.4	18.2	5.7	7.2	1.8	n. d.	12.3		
5	54.18	19.17	6.11	7.05	1.89	n. d.	11.95		
6	56.0	22.1		8.0	1.5	tr.	10.7		2.53
7	57.45	20.56	2.78	4.27	3.17	0.35	8.15		
8	55.96	22.44	2.80	3.78	3.22	0.74	8.03		
9	58.22	17.68	4.48	3.82	2.85	0.43	7.83		
10	57.50	21.70		12.19	1.93	n. d.	n. d.	n. d.	
11	57.82	21.76		8.32	1.81	n. d.	n. d.	n. d.	
12	38.84	17.76		21.58	1.78	n. d.	n. d.	n. d.	
13	50.48	8.89		23.74	2.21	n. d.	n. d.	n. d.	5.68
14	46.54	21.50		11.51	1.88	n. d.	n. d.	n. d.	
15	46.72	22.00		11.82	2.11	n. d.	n. d.	n. d.	
16	56.50	24.50		5.14	1.78	n. d.	n. d.	n. d.	2.31
17	58.10	26.14		3.34	2.01	n. d.	n. d.	n. d.	
18	58.25	24.18		3.46	2.10	n. d.	n. d.	n. d.	
19	61.94	11.58	3.49	5.92	4.85	.18	n. d.	n. d.	
20	56.64	12.18	3.59	8.17	4.29	.31	n. d.	n. d.	
21	61.10	13.91	3.62	6.32	3.91	.31	n. d.	n. d.	
22	59.36	12.38	3.62	5.63	4.62	.30	n. d.	n. d.	
23	53.63	24.47		5.94	1.79	n. d.	10.03		2.19

1. Chicago P. C. Co., Oglesby, Ill. Manufacturer's circular.
2. Marquette Cement Co., Oglesby, Ill. 25th Ann. Rep. U. S. Geol. Survey, pt. 6, p. 544.
3. German-American P. C. Works, La Salle, Ill. W. E. Prüssing, analyst.
4. Iola P. C. Co., Iola, Kansas.
5. " " " "
6. Kansas P. C. Co., Iola, Kansas.
7. Alpena P. C. Co., Alpena, Mich.
8. " " " "
9. " " " "

10–18. Cayuga P. C. Co., Portland Point, N. Y. J. H. McGuire, analyst.
19–22. Bronson P. C. Co., Bronson, Mich. W. H. Simmons, analyst. Vol. 8, Mich. Geol. Survey, p. 239.
23. Virginia P. C. Co., Craigsville, Va. "Cement Industry", p. 235.

beds quite different in composition. They are consequently worked as separate benches or levels, temporary tracks being run in on the upper levels, while the main switch tracks are on the lowest level.

Examination of clay deposits.—Most of the notes in relation to examining limestone deposits presented on an earlier page will apply to the report on a deposit of clay or shale. In sampling, however, the earth-auger can be used much more extensively, as the clayey materials are usually soft enough to be bored readily by such means. For valuable notes on the use of the auger, reference should be made to the papers cited below.*

List of references on clays and shales.—The literature of clays is so extensive that the descriptive papers in the following list have been arranged by States in alphabetical order.

GENERAL UNITED STATES.	Ries, H. The clays of the United States east of the Mississippi River. Professional Paper No. 11, U. S. Geological Survey, 289 pp. 1903.
ALABAMA.	Ries, H., and Smith, E. Preliminary report on the clays of Alabama. Bulletin 6, Alabama Geological Survey, 220 pp. 1900.
ARKANSAS.	Branner, J. C. The cement materials of southwest Arkansas. Trans Am. Inst. Min. Engrs., vol. 27, pp. 42–63.
	Branner, J. C. The clays of Arkansas. Bulletin No. —, U. S. Geological Survey. (In press.)
CALIFORNIA.	Johnson, W. D. Clays of California. 9th Ann. Report California State Mineralogist, pp. 287–308. 1890.
	Ries, H. The clay-working industry of the Pacific Coast States. Mines and Minerals, vol. 20, pp. 487–488. 1900.
COLORADO.	Lakes, A. Gypsum and clay in Colorado. Mines and Minerals, vol. 20. December, 1899.
	Ries, H. The clays and clay-working industry of Colorado. Trans. Am. Inst. Min. Engrs., vol. 27, pp. 336–340. 1898.
FLORIDA.	Memminger, C. J. Florida kaolin deposits. Eng. and Min. Journal, vol. 57, 436 pp. 1894.
	Vaughan, T. W. Fullers' earth deposits of Florida and Georgia. Bulletin 213, U. S. Geological Survey, pp. 392–399. 1903.

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* Bleininger, A. V. The manufacture of hydraulic cements. Bulletin 4, Ohio Geol. Survey, pp. 102–108. 1904. Catlett, C. The hand-auger and hand-drill in prospecting work. Trans. Amer. Inst. Min. Engrs., vol. 27, pp. 123–129. 1898. Jones, C. C. A geologic and economic survey of the clay deposits of the lower Hudson River Valley. Trans. Amer. Inst. Min. Engrs., vol. 29, pp. 40–83. 1900.

GEORGIA.

Ladd, G. E. Preliminary report on a part of the clays of Georgia. Bulletin 6A, Georgia Geological Survey, 204 pp. 1898.

Vaughan, T. W. Fullers' earth deposits of Florida and Georgia. Bulletin 213, U. S. Geological Survey, pp. 392–399. 1903.

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Blatchley, W. S. Clays and clay industries of northwestern Indiana. 22d Ann. Rep. Indiana Dept. Geology and Natural Resources, pp. 105–153. 1898.

IOWA.

Beyer, S. W., and others. Clays and clay industries of Iowa. Vol. 14, Reports Iowa Geol. Survey, pp. 27–643. 1904.

KANSAS.

Prosser, C. S. Clay deposits of Kansas. Mineral Resources U. S. for 1892, pp. 731–733. 1894.

KENTUCKY.

Crump, H. M. The clays and building stones of Kentucky. Eng. and Min. Jour., vol. 66, pp. 190–191. 1898.

LOUISIANA.

Clendennin, W. W. Clays of Louisiana. Eng. and Min. Jour., vol. 66, pp. 456–457. 1898.

Ries, H. Report on Louisiana clay samples. Report Louisiana Geological Survey for 1899, pp. 263–275. 1900.

MARYLAND.

Ries, H. Report on the clays of Maryland. Vol. 4, pt. 3. Reports Maryland Geological Survey, pp. 203–507, 1902.

MASSACHUSETTS.

Whittle C. L. The clays and clay industries of Massachusetts. Eng. and Min. Jour., vol. 66, pp. 245–246, 1898.

MICHIGAN.

Ries, H. Clays and shales of Michigan. Vol. 8, pt. 1. Reports Michigan Geological Survey, 67 pp. 1900.

MINNESOTA.

Berkey, C. P. Origin and distribution of Minnesota clays. Amer. Geologist, vol. 29, pp. 171–177. 1902.

MISSISSIPPI.

Eckel, E. C. Stoneware and brick clays of western Tennessee and northwestern Mississippi. Bulletin 213, U. S. Geological Survey, pp. 382–391. 1903.

MISSOURI.

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NEBRASKA.

Gould, C. N., and Fisher, C. A. The Dakota and Carboniferous clays of Nebraska. Ann. Rep. for 1900, Nebraska Board of Agriculture, pp. 185–194. 1901.

NEW JERSEY.

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New Jersey.

Ries, H., Kümmel, B., and Knapp, G. N. The clays and clay industries of New Jersey. Vol. 6, Final Reports State Geologist, New Jersey. 8vo., 548 pp. 1904.

New York.

Jones, C. C. A geologic and economic survey of the clay deposits of the lower Hudson River Valley. Trans. Am. Inst. Min. Engrs., vol. 29, pp. 40–83. 1900.

Ries, H. Clays of New York. Bulletin 35, New York State Museum, 455 pp. 1900.

North Carolina.

Holmes, J. A. Notes on the kaolin and clay deposits of North Carolina. Trans. Am. Inst. Min. Engrs., vol. 25, pp. 929–936. 1896.

Ries, H. Clay deposits and clay industry in North Carolina. Bulletin 13, N. C. Geological Survey, 157 pp. 1897.

North Dakota.

Babcock, E. J. Clays of economic value in North Dakota. 1st Rep. N. D. Geological Survey, pp. 27–55. 1901.

Ohio.

Orton, E. The clays of Ohio and the industries established upon them. Vol. 5, Reports Ohio Geological Survey, pp. 643–721. 1884.

Orton, E. The clays of Ohio: their origin, composition, and varieties. Vol. 7, Reports Ohio Geological Survey, pp. 45–68. 1893.

Oregon.

Ries, H. The clay-working industries of the Pacific Coast States. Mines and Minerals, vol. 20, pp. 487–488. 1900.

Pennsylvania.

Hopkins, T. C. Clays of western Pennsylvania. Appendix to Ann. Rep. Pennsylvania State College for 1897–98, 184 pp. 1898.

Hopkins, T. C. Clays of southeastern Pennsylvania. Appendix to Ann. Rep. Pennsylvania State College for 1898–99, 76 pp. 1899.

Hopkins, T. C. Clays of the Great Valley and South Mountain areas. Appendix to Ann. Rep. Pennsylvania State College for 1899–1900, 45 pp. 1900.

Woolsey, L. H. Clays of the Ohio Valley in Pennsylvania. Bulletin 225, U. S. Geological Survey, pp. 463–480. 1904.

South Carolina.

Sloan, E. A preliminary report on the clays of South Carolina. Bulletin 1, South Carolina Geological Survey, 171 pp. 1904.

South Dakota.

Todd, J. E. The clay and stone resources of South Dakota. Eng. and Min. Jour., vol. 66, pp. 371. 1898.

Tennessee.

Eckel, E. C. Stoneware and brick clays of western Tennessee and northwestern Mississippi. Bulletin 213, U. S. Geol. Survey, pp. 382–391. 1903.

TEXAS.	Kennedy, W. Texas clays and their origin. Science, vol. 22, pp. 297–300. 1893.
WASHINGTON.	Landes, H. Clays of Washington. Vol. 1, Rep. Washington Geol. Survey, pt. 2, pp. 13–23. 1902.
WISCONSIN.	Buckley, E. R. The clays and clay industries of Wisconsin Bulletin 7, Wisconsin Geol. Survey, 304 pp. 1901.
WYOMING.	Knight, W. C. The building stones and clays of Wyoming. Eng. and Min. Jour., vol. 66, pp. 546–547. 1898.

Slates.

Slate is, so far as origin is concerned, merely a form of shale in which a fine, even, and parallel cleavage has been developed by pressure. In composition, therefore, it will vary exactly as do the shales considered in the last section, and so far as composition alone is concerned, slate would not be worthy of more attention, as a Portland-cement material, than any other shale.

Commercial considerations in connection with the slate industry, however, make slate a very important possible source of cement material. Good roofing slate is a relatively scarce material and commands a good price when found. In the preparation of roofing slate for the market so much material is lost during sawing, splitting, etc., that only about 10 to 25 per cent of the amount quarried is salable as slate. The remaining 75 to 90 per cent is of no service to the slate-miner. It is sent to the dump heap, and is a continual source of trouble and expense. This very material, however, as can be seen from the analyses quoted below, is often admirable for use in connection with limestone in a Portland-cement mixture. As it is a waste product, it could be obtained very cheaply by the cement manufacturer.

Geographic distribution of slates.—The principal areas in the United States in which roofing slate is at present quarried are briefly noted below. For more detailed information on the subject, reference should be made to the papers and reports listed on page 366.

Beginning in the northeast, slates are extensively quarried in the Brownsville-Monson area in northern Maine, but no satisfactory limestones occur in this district The next important slate area lies in western Vermont and eastern New York, a region well supplied with good limestones. In New Jersey and Pennsylvania slates are worked just north of the Lehigh cement-rock belt, as noted in Chapter XXIV. The Peach Bottom slate district, located in southern Pennsylvania and northeastern Maryland, is also important, but is poorly supplied with limestone. Isolated slate districts occur in Virginia, but not near limestone areas. In eastern Tennessee and northwestern Georgia, however, roofing slates and non-magnesian limestones occur in close proximity; and in the Georgia slate district a Portland-cement plant is already in operation. West of the Mississippi, good slates are worked more or less extensively in Minnesota, Arkansas, Utah, and California.

Composition of slates.—The composition of a large series of American roofing slates from various localities is given in Table 164.

TABLE 164

ANALYSES OF AMERICAN ROOFING SLATES.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12	13.	14.
Silica (SiO_2)	54.24	56.42	60.80	67.70	67.76	59.84	67.61	56.49	68.62	55.88	58.37	62.71	60.65	58.20
Alumina (Al_2O_3)	24.71	24.14	22.00	13.49	14.12	15.02	13.20	11.59	12.68	21.85	21.98	19.40	16.87	18.83
Iron oxides (Fe_2O_3,FeO)	8.39	4.46	10.50	2.75	5.52	5.96	6.56	4.90	4.20	9.03	10.66	2.18	7.79	5.78
Lime (CaO)	5.23	0.52	0.50	0.81	0.63	2.20	0.11	5.11	2.34*	0.16	0.30	1.11	1.91	4.35
Magnesia (MgO)	2.59	2.28	0.70	1.29	2.38	3.41	3.20	6.43	3.76*	1.49	1.20	1.73	2.39	3.51
Alkalies	2.15	8.68	2.30	4.91	4.82	5.60	5.12	4.29	3.73	4.10	1.93	4.74	5.98	3.20
Water and CO_2	(?)	3.88	1.80	9.05	3.61	6.83	3.42	10.61	4.47	3.39	4.42	4.08	3.63	4.67

* Carbonate.

1. Monson, Maine.
2. " "
3. Lancaster, Mass.
4. Hamburg, N. Y.
5. West Pawlet, Vt.
6. Pawlet, Vt.
7. Poulteney, N. Y.
8. Raceville, N. Y.
9. Bangor, Pa.
10. Peach Bottom, Pa.-Md. belt.
11. Peach Bottom, Pa.-Md. belt.
12. Martinsburg, W. Va.
13. Arvonia, Va.
14. Rockmart, Ga.

TABLE 165.

COMPOSITION OF AMERICAN ROOFING SLATES.

	Maximum.	Average.	Minimum.
Silica (SiO_2)	68.62	60.64	54.05
Alumina (Al_2O_3)	24.71	18.05	9.77
Iron oxides (FeO,Fe_2O_3)	10.66	6.87	2.18
Lime (CaO)	5.23	1.54	0.00
Magnesia (MgO)	6.43	2.60	0.12
Alkalies (K_2O,Na_2O)	8.68	4.74	1.93
Ferrous sulphide (FeS_2)	.....	0.38	
Carbon dioxide (CO_2)	.....	1.47	
Water of combination	.....	3.51	
Moisture, below 110° C	.....	0.62	

Slates used in cement-manufacture.—Only one American Portland-cement plant is at present using roofing slate as one of its raw materials, and this plant is of quite recent construction. It is that of the Southern States Portland Cement Company, and is located about half a mile east of the village of Rockmart, Polk County, Ga. The Portland cement manufactured here is made from a mixture of pure limestone and slate, both of which materials occur in the immediate vicinity of the plant.

Hard blue slates, which have been extensively quarried for structural purposes, outcrop on the hills south of Rockmart. These slates are of Ordovician age and have been described as the "Rockmart slates" by Hayes. East of the town the surface rock is the "Chickamauga limestone," which here contains beds of pure non-magnesian limestone which have been quarried at several points in the vicinity and burned into lime.

The cement company purchased the property of the old Georgia Slate Company, about half a mile southwest of Rockmart, and carried on extensive operations with the diamond-drill. The intention was to quarry the slate, sell as slate the portions best suited for that use, and utilize the scrap and waste in the manufacture of cement. The quarries from which the limestone is obtained are located half a mile east of town, near the mill. The president of the cement company is Mr. W. F. Cowhan, who is also connected with the Peninsular Portland Cement Company, of Jackson, Mich., and the National Portland Cement Company, of Durham, Ontario.

TABLE 166.

ANALYSES OF SLATE USED FOR PORTLAND CEMENT, ROCKMART, GA.

	1.	2.
Silica (SiO_2)	57.40	58.20
Alumina (Al_2O_3)	23.65	18.83
Iron oxide (CaO)	4.45	5.78
Lime (CaO)	3.23	4.35
Magnesia (MgO)	3.23	3.51
Alkalies (K_2O,Na_2O)	n. d.	3.20
Sulphur (S)	n. d.	0.49
Carbon (C)	n. d.	0.82
Carbon dioxide (CO_2)	6.80	0.60
Water		4.07

1. J. F. Davis, analyst. Privately communicated.
2. Slocum and Vandeventer, analysts. 18th Ann. Rep. U. S. Geol. Survey, pt. 5.

References on slates.—The following papers contain material of interest in connection with the composition, distribution, and structure of slate.

Dale, T. N. The slate belt of eastern New York and western Vermont. 19th Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 153–307. 1899.

Dale, T. N. The slate industry at Slatington, Pa., and Martinsburg, W. Va. Bulletin 213, U. S. Geol. Survey, pp. 361–364.

Dale, T. N. The slate deposits and slate industry of the United States. Bulletin —, U. S. Geol. Survey. (In press.)

Davies, D. C. Slate and slate quarrying. 12mo, 181 pp. London, 1899.

Eckel, E. C. Slate deposits of California and Utah. Bulletin 225, U. S. Geol. Survey, pp. 417–422. 1904.

Eckel, E. C. The chemical composition of American shales and roofing slates. Journal of Geology, vol. 12, pp. 25–29. 1904.

CHAPTER XXVIII.

EXCAVATING THE RAW MATERIALS.

The excavation of the raw materials is the first step toward the actual manufacture of Portland cement, and the one concerning which least has been published. Local conditions enter into this preliminary phase to such an extent that few general statements can be made concerning it. To a large extent, each separate deposit of raw material is an individual proposition to be handled best in a way peculiar to itself. The natural raw materials which are at present used in the American Portland-cement industry are worked by one of three general methods. These are: (1) quarrying or digging from open pits; (2) mining from underground workings, and (3) dredging from deposits covered by water. Occasionally the cement manufacturer will have an opportunity to choose his general method of working the deposit, in which case his choice will depend partly on the physical characters of the material to be excavated and partly on the topographic and geologic conditions. Usually, however, he will have no opportunity to choose a method, for in any given case one of the methods will be so evidently the only possible mode of handling the material as to leave no room for other considerations.

The three different general methods of excavation will first be briefly considered, after which the cost of excavating various raw materials will be discussed in some detail.

Quarrying.

In the following pages the term "quarrying" will be used to cover all methods of obtaining raw materials from open excavations—quarries, cuts, or pits—whether the material excavated be a limestone, a shale, or a clay. Quarrying is the most natural and common method of excavating the raw materials for cement-manufacture. If marl, which is usually worked by dredging, be excluded from consideration, it is probably within safe limits to say that 95 per cent of the raw materials used at American Portland-cement plants are obtained by quarrying. If marls be included, the percentages excavated by the different methods would probably be about as follows: quarrying, 88 per cent; dredging, 10 per cent; mining, 2 per cent.

Stripping.—When a limestone is being quarried, the opening should be so located as to give as little stripping as possible in proportion to the available rock; for in this case the stripping is merely dead work, adding greatly to the expense of the product. In dealing with a shale-bed, the "stripping" is usually merely weathered shale and can be used as well as the harder portions of the deposit.

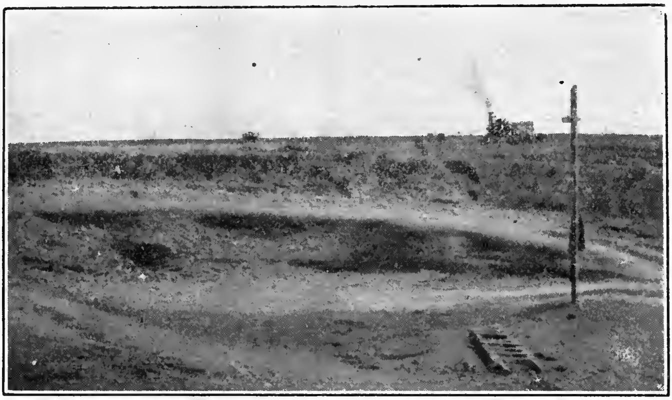

Fig. 71.—Stripping a flat, shallow bed.

A very thick bed of limestone, or a bed of moderate thickness lying almost horizontally, will not give as much stripping per ton of good rock as a thin bed or a bed dipping at a high angle. In handling comparatively thin earth stripping in flat country, scrapers or excavators may be used (Fig. 71); while at one cement-plant a heavy soil cover on a quarry near a river-bank is removed by hydraulicking. This last process is also used in several large brick-plants.

Quarry practice.—In most of the quarries for cement rock or limestone, the rock is opened up on a low side-hill, so as to give a long working-face with light stripping and as little grade as possible in the workings. The rock is blasted down in one or more benches, according to the height of face exposed, and the larger pieces are sledged or reblasted to manageable size by men placed along the working-face. It is then loaded either into one-horse carts or into small cars running on temporary tracks laid close up to the face. In the former case the carts are driven to a dump and loaded into cars; in the latter case the cars are drawn by horses or pushed by men to a turntable. This turntable

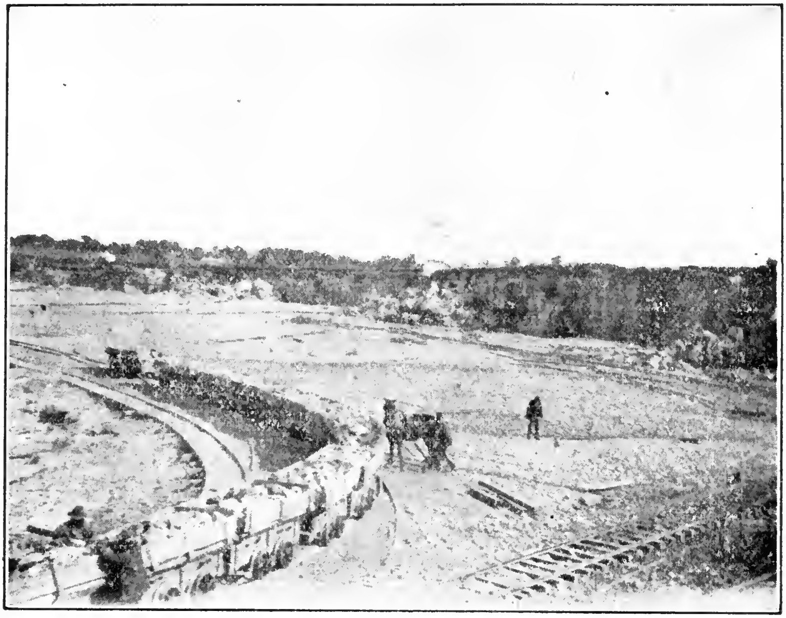

FIG. 72.—View of typical quarry.

FIG. 73.—Temporary tracks laid to face.

is a comparatively fixed affair, located far enough away from the working-face to avoid damage from blasting. Here the cars are attached to a cable or to a locomotive and hauled to the mill.

Fig. 74.—Cableway in cement-rock quarry.

Occasionally an aerial cableway is used for transporting the material to the mill. This is shown in the two views of a cement-rock quarry given in Figs. 74 and 75.

Working in levels.—In quarries containing several beds of rock differing greatly in composition and lying horizontally, tracks are often run in on different levels, so as to insure that each car or cart shall contain only one kind of rock. This practice is exemplified in the shale-pit shown in Fig. 76. A similar plan is followed in working the quarry partly shown in Fig. 77, which contains several heavy beds of limestone intercalated with workable but thinner layers of shale.

Use of steam-shovels.—In a few limestone and cement-rock quarries a steam-shovel is employed to load the blasted rock into the cars, and in shale quarries this use of steam-shovels is more frequent. In certain clay- and shale-pits, where the material is of suitable character, the steam-shovel can be employed to do all the work, both excavating and loading the materials.

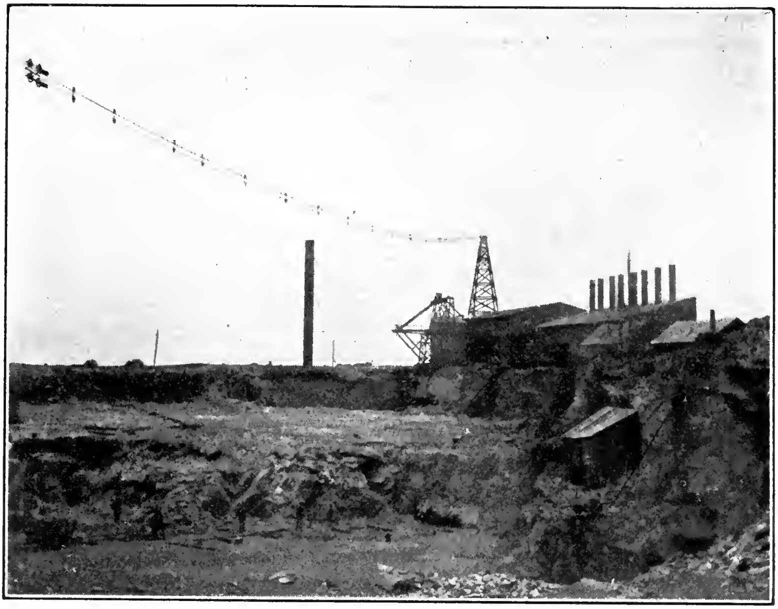

Fig. 75.—Cableway in cement-rock quarry.

Fig. 76.—Shale-pit worked in two levels.

FIG. 77.—Hoisting from quarry worked in levels.

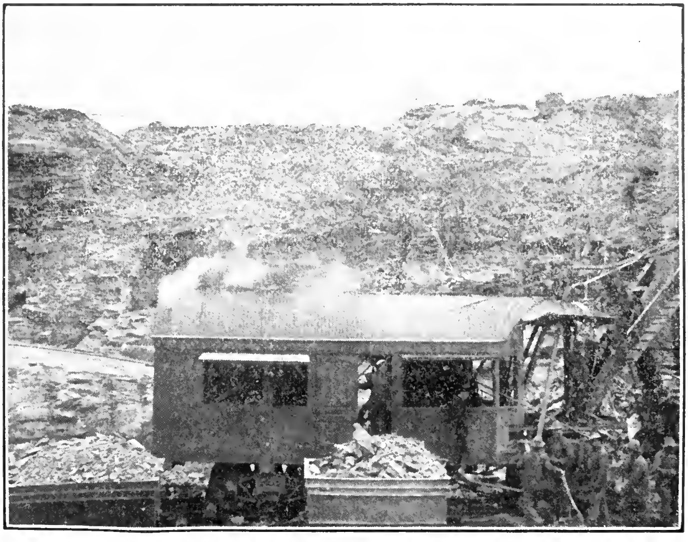

FIG. 78.—Steam-shovel in cement-rock quarry.

Steam-shovels are in use at the plant of the Purington Paving Brick Company, at Galesburg, Ill. Here a bank of firm shale is drilled, shaken with black powder, and then handled entirely by steam-shovel. The following detailed figures of cost have been recently published by Mr. C. W. Purington.

The figures cover the handling of 17,422 cubic yards of shale in one month of twenty-six nine-hour days. This shale was dug from a 50-foot bank with a Model 90 Barnhart shovel with 2-yard dipper. It was delivered to twenty 2-yard cars and trammed in two directions (1500 and 2000 feet respectively) to the bottoms of two inclines. It was then hoisted by cable to hoppers placed at an elevation of 20 feet above the track and dumped into the hoppers.

TABLE 167.

DETAILED COSTS OF STEAM-SHOVEL WORK. (PURINGTON.)

		Per Month.	Per Yard, Cents.
Labor	1 engineer on shovel	$110.00	
	1 craneman	85.00	
	1 fireman at 22½ cents per hour	52.65	
	3 trackmen at 17½ cents per hour	128.85	
	1 engineer on locomotive	80.00	
	1 switchman at 20 cents per hour	46.80	
	2 hoistmen at 20 cents per hour	93.60	
	Total labor	$596.90	0.0343
Fuel	1½ tons coal per day at $2.00 per ton for shovel	78.00	
	½ ton coal per day at $2.00 per ton for locomotive	26.00	
	1 ton coal per day at $2.00 per ton for two hoists	52.00	
	Total fuel	$156.00	0.0089
	Total costs, labor and fuel	$752.90	0.0432

These figures do not include charges for superintendence, oil, waste, etc. If these be included, the cost of the steam-shovel work will be about 5 cents per cubic yard. If the cost of drilling and blasting be added, the total cost of handling the shale from the bank to the hoppers may be about 6 cents per cubic yard. Of this the blasting, digging, etc., amounts to about 4 cents per yard, while the tramming, hoisting, and dumping will amount to the remaining 2 cents.

In handling shales, steam-shovels are usually very effective excavators, for here the material is physically homogeneous and requires only one light blasting to break it into fragments that can be readily handled by the shovel. This is well brought out by the itemized costs given above for the Galesburg shale quarry.

When dealing with the Lehigh district cement rock, the steam-shovel is not quite so satisfactory, for much of the rock will require hand sledging after being blasted before it can be conveniently handled by the shovel. The hard limestones are still more intractable, and often require not only sledging but reblasting. This, of course, greatly decreases the financial effectiveness of the shovel, and in many quarries will entirely prevent its use. In shallow quarries vertical seams filled with clay, soil, or other wash from the surface may greatly hinder the work of the shovel; and in quarries where rock is so mixed in composition as to require sorting the shovel is worse than useless.

FIG. 79.—Steam-shovel handling limestone.

Crushing and drying in the quarry.—The rock is usually transported directly to the mill just as quarried, except that the larger masses are sledged to convenient size for handling. At a few quarries, however, a crushing-plant is installed at the quarry, and the rock is sent as crushed stone to the mill. Several of the quarries in question sell a certain portion of their product as road metal, which, of course, reduces the cost of the finer material which is sent to the cement-plant.

A few plants have also installed their driers at the quarry and dry the stone before shipping it to the mill. This practice, shows a saving in mill space, but otherwise it seems to have little to recommend it.

In the cases where a wet clay or shale is quarried some distance away from the mill the saving in transportation charges, due to drying at the quarry, would, of course, be considerable.

Mining.

The term "mining" will be used, in distinction from "quarrying", to cover methods of obtaining any kind of raw material by underground workings, through shafts or tunnels. Mining is rarely employed in excavating materials of such low value per ton as the raw materials for Portland-cement manufacture. Occasionally, however, when a thin bed of limestone or shale is being worked, its dip will carry it under such a thickness of other strata as to make mining cheaper than stripping and quarrying for that particular case.

Mining is considerably more expensive work than quarrying, but there are a few advantages about it that serve to counterbalance the greater cost per ton of raw material. A mine can be worked steadily and economically in all kinds of weather, while an open cut or quarry is commonly in a more or less unworkable condition for about three months of the year. Material won by mining is, moreover, always dry and clean.

Dredging.

The term "dredging" will be here used to cover all methods of excavating soft, wet, raw materials. The fact that the materials are wet implies that the deposit occurs in a basin or depression, and this in turn implies that the mill is probably located at a higher elevation than the deposit of raw material, thus necessitating uphill transportation to the mill.

The only raw material for Portland-cement manufacture that is extensively worked by dredging in the United States is marl. Occasionally the clay used is obtained from deposits overlain by more or less water; but this is rarely done except where the marl and clay are interbedded or associated in the same deposit.

A marl deposit, in addition to containing much water diffused throughout its mass, is usually covered by a more or less considerable depth of water. This will frequently require the partial draining of the basin in order to get tracks laid near enough to be of service.

In dredging marl the excavator is frequently mounted on a barge which floats in a channel resulting from previous investigation. Occasionally, in deposits which either were originally covered by very little water or have been drained, the shovel is mounted on a car running on tracks laid along the edge of the deposit.

The material brought up to the dredge may be transported to the mill in two different ways, the choice depending largely upon the manufacturing processes in use at the plant. At plants using dome or chamber kilns, or where the marl is to be dried before sending to the kiln, the excavated marl is usually loaded by the shovel on cars and hauled to the mill by horse or steam power. At normal marl-plants using a very wet mixture it is probable that the second method of transportation is more economical. This consists of dumping the marl from the excavator into tanks, adding sufficient water to make it flow readily, and pumping the fluid mixture to the mill in pipes.

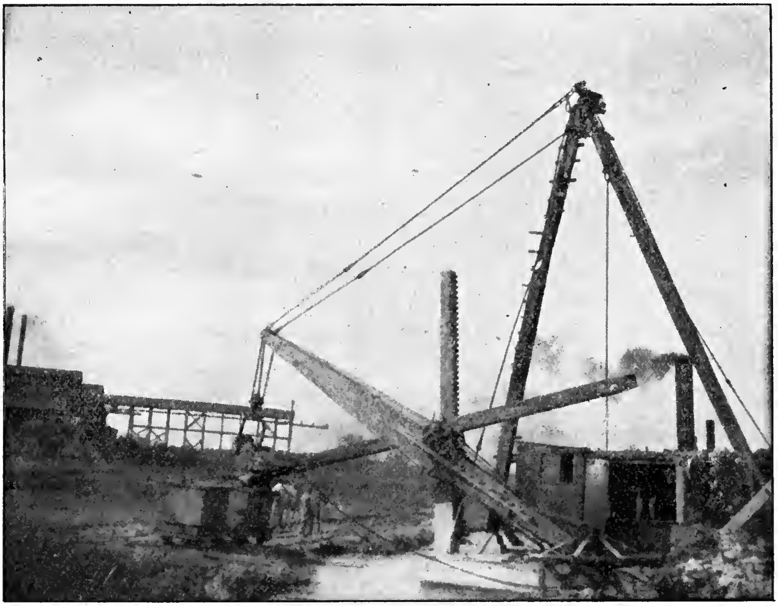

FIG. 80.—Dredge at marl-plant.

Marl-pumping.—The following description of the Harris system of pumping marl from the lake to the mill is taken from the catalogue of the Allis-Chalmers Company:

"This method of handling marl by compressed air is now in great favor, and many plants have been and are now being installed in cement works in this country and Canada.

"The essential features are given in the diagram herewith, and comprise the pump-tanks, air-compressor, automatic switch, and piping. There are no floats. There are no air-valves outside the engine-room.

"The air is not allowed to escape after doing its work. The expansive force of the air is used in the compression cylinder of the compressor, thus giving back the greater part of its energy to the compressor.

"Suppose the compressor to be in operation with switch set as in the figure, the air will be drawn out of the right-hand tank and forced into the left-hand tank, and in so doing will draw marl into the former and force it out of the latter.

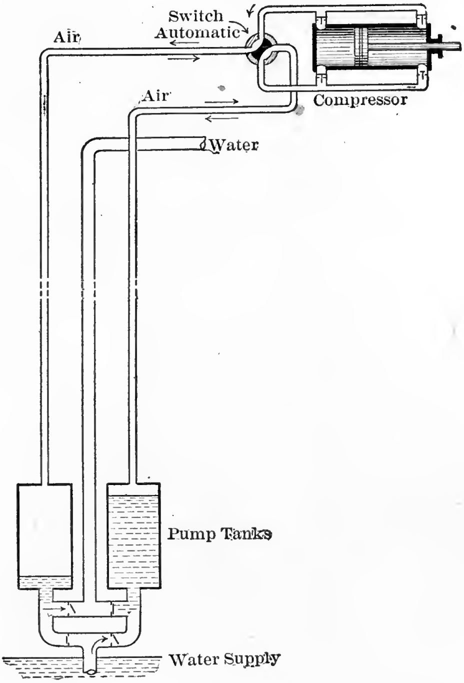

FIG. 81.—Harris system of marl-pumping.

"The charge of air in the system is so adjusted that when one tank is emptied the other is just filled. At that moment the switch will reverse the pipe connections so that action in the tanks will be reversed.

"The switch is adjustable and can be set or regulated while the pump is in operation."

For further data, reference should be made to a paper by E. G. Harris, published in "Mines and Minerals," vol. 15, pp. 513–514. May, 1905.

Cost of Raw Materials at Mill.

The most natural way, perhaps, to express the cost of the raw materials delivered at the mill would be to state it as being so many cents per ton or cubic yard of raw material; and this is the method followed by quarrymen or miners in general. To the cement manufacturer, however, such an estimate is not so suitable as one based on the cost of raw materials per ton or barrel of finished cement.

Loss on drying, etc.—In the case of hard and comparatively dry limestones or shales, it may be considered that the raw mixture loses 33⅓ per cent in weight on burning. Converting this relation into pounds of raw material and of clinker, we find that 600 pounds of dry raw material will make about 400 pounds of clinker. Allowing something for other losses in the process of manufacture, it is convenient and sufficiently accurate to estimate that 600 pounds of dry raw material will give one barrel of finished cement. These estimates must be increased if the raw materials carry any appreciable amount of water. Clays will frequently contain 15 per cent or more of water; while soft, chalky limestones, if quarried during weather, may carry as high as 15 to over 20 per cent. A Portland-cement mixture composed of a pure chalky limestone and a clay might, therefore, average 10 to 20 per cent of water, and consequently about 700 pounds of such a mixture would be required to make one barrel of finished cement.

With marls the loss on drying and burning is much greater. Russell states * that according to determinations made by E. D. Campbell, 1 cubic foot of marl as it usually occurs in the natural deposits contains about 47½ pounds of lime carbonate and 48 pounds of water. In making cement from a mixture of marl and clay, therefore, it would be necessary to figure on excavating and transporting over 1000 pounds of raw material for every barrel of finished cement.

From the preceding notes it will be understood that the cost of raw materials at the mill per barrel of cement will vary not only with the cost of excavation, but with the kind of materials in use.

Costs of quarrying or mining.—In dealing with hard, dry materials extracted from open quarries near the mills, the cost of raw materials may vary between 8 cents and 15 cents per barrel of cement. The lower figure named is probably about the lowest attainable with good management and under favorable natural conditions; the higher figure

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* 22d Ann. Rep. U. S. Geol. Survey, pt. 3, p. 657.

is probably a maximum for fairly careful management of a difficult quarry under Eastern labor conditions.

At one Portland-cement plant in the Middle States a 20-foot limestone-bed, overlain by 10 to 15 feet of shale and soil, is worked in open cut. When this work was handled by contract, 18 cents per cubic yard was paid for stripping, and 23 cents per ton for quarrying rock. Haulage to the mill, only a quarter of a mile away, cost about 4 cents per ton, owing to local difficulties. Quarry laborers here were worth $1.50 per day, and the following data on actual cost of quarrying were obtained from one of the contractors. The items cover labor and supplies for two men for two weeks, during which time the pair got out 300 tons of limestone.

10 lbs. dynamite at $0.14 per lb.	$1.40
¼ box caps at $0.75 per box.	0.19
1 keg powder at $1.50 per keg.	1.50
100 feet fuse at $0.45 per 100 feet.	0.45
Repairs, sharpening, etc.	0.60
24 days' labor at $1.50 per day	36.00
Cost of quarrying 300 tons limestone	$40.14
Cost of quarrying, per ton limestone.	0.13+
" " stripping, " " "	0.07
" " hauling, " " "	0.04
Total cost limestone per ton.	$0.24

When it is necessary to mine the materials, the cost will be somewhat increased. Natural-cement rock has been mined at a cost equivalent to 10 cents per barrel of cement; but the figure is attained under particularly favorable conditions. The cost of mining and transportation may reach from this figure up to 20 cents per barrel.

Costs of marl-dredging.—The costs of dredging and handling marl at several American cement-plants are given below:

Plant 1. The marl- and clay-pits are about 3½ miles by track from the mill. Both materials are covered by ½ to 1 foot of earth, but no water. A long cut is made into the deposit, into which cut cars are run on light tracks. These cars, containing about 3000 lbs. of marl, are loaded by hand. The contract price for loading is 8 cents per car for marl and 14 cents per car for clay, and these prices are equivalent to a pay of $3.00 to $4.00 per day of 12 hours for each laborer loading. Two engines are used, one for switching and making up trains at the marl- and clay-pits, the other for hauling the trains to the mill. The total cost for sufficient marl and clay for 1200 barrels cement is:

2	engineers at $1.50	$3.00
2	firemen at $1.25	2.50
400	cars marl at $0.08	32.00
80	cars clay at $0.14	11.20
2000	lbs. coal at $2.40 per ton	2.40
	Total cost marl and clay for 1200 bbls. cement	$51.10
	Cost marl and clay for 1 bbl. cement	0.043

Plant 2. The marl and clay occur in a swamp half a mile from the mill. The surface material is 2 to 3 feet black loam; this is underlain by 9 feet marl, and this, in turn, by the clay. A dredge with a 15-H.P. engine and a crew of two men handles the marl, digging enough for 240 barrels cement in ten hours. A smaller dredge with orange-peel bucket, run by one man, handles the clay. One locomotive hauls the material to the plant over tracks laid alongside the excavations. Total costs per day for a 240-barrel plant are as follows:

1	marl-dredge runner	$1.50
1	leverman, marl dredge	1.25
1	clay-dredge runner	1.25
1	locomotive engineer	1.50
350	lbs. coal for marl dredge at $2.20 per ton	0.38½
150	lbs. coal for clay dredge at $2.20 per ton	0.16½
500	lbs. coal for locomotive at $2.20 per ton	0.55
	Cost of clay and marl for 240 barrels cement	$6.50
	Cost of clay and marl for 1 barrel cement	0.027

Plant 3. Marl dredged from lake one quarter mile from mill. This is done by contract, the marl being delivered to the mill for 5¼ cents per cubic yard. This price is about equivalent to $0.018 per barrel of cement *for marl alone.* In this case the dredging-plant was bought and installed at the expense of the company, but the contractor pays all the current expenses, including pay, repairs, coal, etc.

Plant 4. Marl dredged from lake one third mile from mill by a dredge operating a 1½-cubic-yard orange-peel bucket. The marl is fed through a stone separator and then pumped to the mill on Harris system. Total cost is about as follows:

2 men at $1.50	$3.00
3 men at $1.25	3.75
2½ tons coal at $2.40	6.00
Total cost of marl for 500 barrels cement	$12.75
Cost of marl for 1 barrel cement	0.025

The costs above cited show the cheapness with which marl and clay can be excavated. The total costs of raw material at a wet-process plant may therefore range from 3 to 6 cents per barrel of cement.

References on quarrying, etc.—The following books and papers contain data of interest on methods and costs of quarrying, etc.

Crane, W. A. Shale Mine at La Harpe, Kansas. Mines and Minerals, Dec., 1902, pp. 217–218.

De Kalb, C. Manual of Explosives. 16mo, 126 pp. Ontario Bureau of Mines, 1900.

Foster, C. Le Neol. Elements of Mining and Quarrying. 12mo, 321 pp. 1903.

Gillette, H. P. Earthwork and Its Cost. 12mo, 244 pp. New York, 1903.

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Green, N. M. [Cost of raw materials in cement manufacture.] Engineering Record, Jan. 23, 1904.

Guttmann, O. Blasting. 8vo, 179 pp. London, 1892.

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Knight, W. B. Quarrying Limestone at Rockland, Maine. Mines and Minerals, August, 1899.

CHAPTER XXIX.

CALCULATION AND CONTROL OF THE MIX.

If, as in the present volume, we exclude from consideration the so-called "natural Portlands" (see page 215), Portland cement may be regarded as being entirely an artificial product, obtained by burning to semi-fusion an intimate mixture of pulverized materials, this mixture containing lime, silica, and alumina varying in proportion only within certain narrow limits, and by crushing finely the clinker resulting from this burning.

If this restricted definition of Portland cement be accepted, four points may be regarded as being of cardinal importance in its manufacture. These are:

1. The cement mixture must be of the proper chemical composition.
2. The materials of which it is composed must be carefully ground and intimately mixed before burning in order to insure that chemical combination shall take place after calcination.
3. The burning must be conducted at the proper temperature, which varies considerably according to the chemical composition of the mixture, and the length of time during which it is subjected to the burning process.
4. After burning, the resulting clinker must be finely ground.

In this and the succeeding chapters these points will be taken up separately and in some detail.

The present chapter deals with the calculations and arrangements necessary for insuring the correctness of the cement mixture. It, therefore, includes discussions of the theoretical and practical considerations which determine the proportions of the mixture. Among these considerations are the theoretical composition and constitution of Portland cement; the influence of various normal constituents on the properties of the mixture; the influence of fuel ash and other accidental impurities; and the methods of calculating and controlling the mix in actual practice.

Theoretical Composition of Portland Cement.

During recent years much attention has been paid by various investigators to the constitution of Portland cement. The chemical composition of any particular sample can, of course, be readily determined by analysis, and by comparison of a number of such analyses, general statements can be framed as to the range in composition of good Portland cements. This subject is discussed further in Chapter XXXVIII, where a large number of analyses are presented.

Chemical analyses will determine what ingredients are present, and in what percentages, but other methods of investigation are necessary to ascertain in what manner these ingredients are combined. A summary of the more important practical results brought out by these investigations on the constitution of Portland cement will be given in the present chapter, while in Chapter XXXVIII a more detailed discussion of the problem will be presented, as well as references to the principal papers on the subject.

It would seem to be firmly established that in a well-burned Portland cement much of the lime is combined with most of the silica to form the compound $3CaCO,SiO_2$,—tricalcic silicate. To this compound is ascribed, in large measure, the hydraulic properties of the cement; and in general it may be said that the value of a Portland cement increases directly as the proportion of $3CaO,SiO_2$. The ideal Portland cement, toward which cements as actually made tend in composition, would consist exclusively of tricalcic silicate, and would be therefore composed entirely of lime and silica in the following proportions:

Lime (CaO)	73.6
Silica (SiO_2)	26.4

Such an ideal cement, however, cannot be manufactured under present commercial conditions, for the heat required to clinker such a mixture cannot be attained in any working kiln. The oxyhydrogen blowpipe and the electrical furnace will give clinker of this composition; but a pure lime-silica Portland is not possible under present conditions as to burning and grinding on a commercial scale.

In order to prepare Portland cement in actual practice, therefore, it is necessary that some other ingredient or ingredients should be present to serve as a flux in aiding the combination of the lime and silica, and such aid is afforded by the presence of alumina and iron oxide.

Alumina (Al_2O_3) and iron oxide (Fe_2O_3) when present in noticeable percentages serve to reduce the temperature at which combination of the lime and silica (to form $3CaO,SiO_2$) takes place; and this clinkering temperature becomes further and further lowered as the percentages of alumina and iron are increased. The strength and value of the product, however, also decrease as the alumina and iron increase; so that in actual practice it is necessary to strike a balance between the advantage of low clinkering temperature and the disadvantage of weak cement, and to thus determine how much alumina and iron should be used in the mixture. This point will be further discussed on later pages.

It is generally considered that whatever alumina is present in the cement is combined with part of the lime to form the compound $2CaO,Al_2O_3$,—dicalcic aluminate. It is also held by some, but this fact is somewhat less firmly established than the last, that the iron present is combined with the lime to form the compound $2CaO Fe_2O_3$. This question of the action of the iron will be later referred to. For the purposes of the present chapter it will be sufficient to say that in the relatively small percentages in which iron occurs in Portland cement it may for convenience be considered as approximately equivalent to alumina in its action.

Influence of Normal Constituents on the Cement.

Lime, silica, alumina, iron oxide, magnesia, sulphur, and alkalies may be regarded as being normal constituents of any Portland-cement mixture. The three first named are necessary ingredients, while the last two, though undesirable, are rarely entirely absent from the raw materials used. The influence exerted by greater or lesser proportions of these seven constituents on the properties of both mixture and finished cement will be discussed in the present chapter.

Maximum lime content of mixture.—On pages 392–393 Newberry's method of proportioning cement mixtures will be described and exemplified. It should be borne in mind, however, that the Newberry formula there quoted will, if followed, give the *maximum* lime content that the mixture could bear, *providing* that the grinding, mixing, and calcination were performed with absolute perfection. As a matter of fact, however, the lime content of the mixture should never be carried quite as high as this formula would indicate, for in actual practice the mixing, grinding, and calcination are never theoretically perfect, and in consequence of a perfect combination of all the lime with all the silica and alumina cannot be attained. There will always remain a certain amount of uncombined material. If therefore, the lime in the mixture is carried as high as is theoretically allowable, a certain amount of free lime will occur in the cement. If, on the other hand, the mixture carries less than its proper theoretical percentage of lime, the cement will, of course, contain some uncombined silica or alumina. A choice must be made, therefore, between the possibilities of having free lime in the product and having uncombined clayey matter. This choice is simple, for the effects on the value of the cement of these two possibilities are very different. Free lime is positively dangerous to the cement, while free clayey materials are merely inert, their only effect being to lower the tensile strength of the product. For this reason, since in practice it is necessary to choose between the two contingencies (free lime *vs.* free silica and alumina), the lime content of the mixture is always carried lower than theoretical considerations demand.

It is to be further noted in this connection that the lime content of Portland cements relatively high in silica may be carried higher than in the case of the more aluminous Portlands. In discussing the constitution of Portland cement in preceding paragraphs it was stated that though lime combines with both silica and alumina, the combining proportions are very different in the two cases. With silica, lime forms the tricalcic silicate, whose percentage composition is lime 73.6 per cent, silica 26.4 per cent; the lime and silica are therefore combined in the proportion of lime 2.8 to silica 1. With alumina, lime forms a less basic compound, the dicalcic aluminate. The percentage composition of this compound is lime 52.3 per cent, alumina 47.7 per cent, corresponding about to the proportion lime 1.1 to alumina 1. It is evident, therefore, that a mixture containing 20 per cent silica and 5 per cent alumina can safely carry more lime than one containing 15 per cent silica and 10 per cent alumina.

Since the combination of lime, silica, and alumina becomes more thorough in proportion as the mixing, grinding, and burning are better done, higher lime contents can be carried by carefully prepared mixtures than by careless or coarsely ground mixtures; and in rotary-kiln plants lime may be carried higher than in those using dome kilns.

Up to the limit of safety every increase in the percentage of lime in the mixture will cause, other things being equal, an increase in the strength of the cement. This fact is taken advantage of, particularly when a new brand is being placed on the market. The usual method of procedure at such a time is to carry the lime very high, burn very hard, and pulverize very fine. This makes a costly but high-testing cement. As soon as the brand has become well established, the lime content can be dropped to reasonable working limits.

Minimum lime content of mixture.—The maximum lime content of the mixture is fixed by the considerations set forth in the preceding paragraphs. The minimum lime content, however, will also require some consideration. Low lime will invariably mean low-testing cements, and in the present state of the industry, low-testing cements are not easily marketed. A low-lime content is also the cause, in part, of the "dusting" of clinker in the vertical kiln. Le Chatelier found that the dicalcic silicate ($2CaO,SiO_2$) possesses the property of spontaneously disintegrating on cooling. If the lime content of the mixture be carried too low, therefore, the clinker will fall to dust in the kiln, owing to the production of this unstable dicalcic silicate.

Magnesia.—The question as to the percentage of magnesia allowable in a Portland cement has given rise to serious controversy for many years. In Europe the tendency has been to keep it below 3 per cent; but in this country, largely because of the results attained by Lehigh Valley cements above this limit, 4 or 5 per cent has been considered the allowable maximum. All this discussion was carried on under the idea that magnesia was either inert or positively harmful in a Portland cement.

Recent experiments by Prof. Newberry, however, have proven that an entirely satisfactory cement can be made carrying as high as 10 per cent of magnesia, if due care be given to the mixing and burning. This might have been expected, both on theoretical grounds and because of the evidently active nature of magnesia in even the highest-burned natural cements, as pointed out on pages 198–200. At present it seems safe to say that magnesia can be considered equivalent to lime in its action, if due allowance be made for the difference in their combining weights. It is therefore theoretically possible to prepare a series of lime-magnesia Portlands, parallel to our present lime Portlands; and it is probable enough that in a few years some move will be made in this direction. But it must be borne in mind that a lime-magnesia Portland will probably differ in important respects from our present lime Portlands, and that it will therefore be inadvisable to group the two types of cement under the same general name. For this reason, in the present volume, the term Portland has been restricted by definition to apply only to cements carrying less than 5 per cent of magnesia (MgO).

Silica.—It is commonly considered that the ultimate strength of the cement depends in large part upon the amount of calcium trisilicate it contains. Within certain limits, therefore, any increase in the percentage of silica in the mixture will increase the strength of the cement. On the other hand, an increase in silica will usually imply a decrease in alumina and iron oxide, and this in turn will cause the cement to be slow-setting (which is an advantage), but hard to clinker.

Alumina.—To the calcium aluminate of a cement are ascribed the initial setting properties. Decrease in the alumina, therefore, tends to make the cement slower setting, while high alumina affects it in the opposite way. Though it is advisable to carry the alumina as low as possible, so as to secure slowness of set and greater ultimate strength, it is impossible to carry it below a certain minimum, for alumina aids greatly in securing a low clinkering temperature, and a cement very low in alumina will clinker only with great difficulty. Too much alumina, on the other hand, will give a very fusible and sticky clinker, liable to ball in the kiln.

Le Chatelier considers that the aluminous compounds present in Portland cement are the direct cause of its destruction by sea-water. His theory to account for this disintegration is as follows: Free lime, liberated during the hardening of the cement, reacts with the magnesium sulphate always present in sea-water, to form calcium sulphate. This in turn reacts with the calcium aluminate of the cement to form a sulphaluminate of lime, which swells considerably on hydration and thus disintegrates the cement mass. The extent of the disintegration varies directly with the percentage of alumina present in the cement. Cements containing 1 or 2 per cent of alumina are, for example, practically unaffected by sea-water, while in cements containing as high as 7 or 8 per cent of alumina the swelling and consequent disintegration are very rapid.

If the alumina of a cement be replaced by an oxide not reacting with calcium sulphate, the stability of the cement in sea-water is greatly improved. Le Chatelier has demonstrated this by preparing cements in which the alumina was replaced by oxides of iron, chromium, cobalt, etc. All of these were more resistant than an alumina cement to the disintegrating effect of lime sulphate. The best effects were obtained when iron oxide was used, a cement corresponding in composition to $5SiO_2,Fe_2O_3,17CaO$ being found to be not only stable in presence of sea-water but to possess excellent mechanical properties.

Deval's researches * on the effect of direct addition of calcium sulphate to various cements confirm the above theory. Each of the finely ground cements tested was completely hydrated by mixing with 50 per cent of water and storing the mixture under water for three months out of contact with carbon dioxide. The mass was then dried, reground, mixed with half its weight of calcium sulphate and 33 per cent of water, and made up into rods which were kept moist and protected from car-

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* Abstract in Jour. Soc. Chem. Industry, vol. 21, pp. 971–972.

bon dioxide by storage on moistened filter-paper under a glass bell. At the end of three weeks the increase in length of the rods was measured with the following results.

TABLE 168.

EFFECT OF ALUMINA.

Type of Cement.	Per Cent of Alumina in Cement.	Per Cent of Elongation of the Rods.
Slag cement (Vitry)	15.5	27
" " (Champignolles)	14.5	16
Grappier cement (Besses)	7.5	14
Portland cement	6.2	12
Hydraulic lime (Besses)	4.7	4

It will be noted that the percentage of elongation of the rods varied directly with the percentage of alumina in the cements tested, proving conclusively that the swelling was due to the action of the calcium sulphaluminate formed during the operation.

Iron oxide.—Iron oxide, though usually so low as to be negligible in a Portland cement, occasionally is present in considerable percentages (4 to 6 per cent). When this is the case, it can only be considered as equivalent to alumina in its action, allowing, of course, for their difference in combining weights. This conclusion is borne out by the fact that Portland cements practically free from alumina have been made, containing lime, silica, and iron oxide only.

Sulphur.—Sulphur, when present in a cement mixture, may occur either as a sulphide or sulphate. In the former condition it is usually due to the occurrence of pyrite (iron disulphide, FeS_2) either in the limestone or in the clay. When present as a sulphate, it is usually in the form of gypsum (hydrous calcium sulphate, $CaSO_4+2H_2O$).

In the rotary kiln, which usually has an abundantly oxidizing flame, it is probable that any calcium sulphate present is dissociated ($CaSO_4 = CaO+SO_3$) and the sulphur trioxide carried off, as this dissociation occurs at a temperature much lower than that reached in clinkering. If the flame is not sufficiently oxidizing, however, and because of imperfect draft this condition is likely to occur in vertical kilns, any lime sulphate present will be reduced to the sulphide form.

Alkalies.—Small percentages of soda and potash are usually present in the mixture, due mostly to their presence in the clay or shale. Alkalies have been regarded as detrimental, as inert, and as beneficial; and much discussion has taken place on the subject, based mostly on purely theoretical considerations.

In experimenting with various methods for analyzing Portland cement, Hillebrand encountered the question of loss of alkalies during burning, which he discusses * as follows:

"Long before the last of the sulphur trioxide is expelled alkali begins to volatilize, and it is easy to remove all or nearly all in this manner. The alkali is volatilized as oxide and may be collected in quantity on the under side of the crucible lid. At the intense temperature of the rotary-kiln furnace this action must play an important part, and to it is to be attributed the great loss of alkali noted by me in the cement of 1901, as compared with the raw mix from which it was made, an observation which is repeated in the present case and must be general in cement-burning."

Phosphorus.—Phosphorus, combined with lime in the form of lime phosphate, frequently occurs in notable percentages in limestones, particularly in the soft, chalky limestones and "marls" of the Southern States. In analyses this will be reported as phosphoric acid or phosphorus pentoxide (P_2O_5), when it is determined at all. Few commercial analysts, however, would look for it in a cement material, and it is therefore rarely reported.

Late in 1903 samples of a "marl" and clay from a Southern State were sent to a leading testing laboratory to obtain a decision on their value as cement materials. Three different burnings of cement were made from the raw materials in various mixtures, and the resulting cements gave the tests shown in Table 172, below. In addition to these generally poor results the chemists reported that the cement, for a week or so after setting, was so soft that it could be readily rubbed off by the hand. The various defects in the cements were ascribed by the laboratory experts to the presence in the marls of notable percentages of phosphoric acid. The matter was referred to me by the Southern company, and at my request Prof. Clifford Richardson examined microscopically several thin sections of the clinker which had been made in the laboratory tests. He reported that the raw mix had been very coarsely ground and the clinker underburned.

The raw materials, as analyzed at the laboratory, showed the results given in Table 169. Two samples of marl were tested and one of clay.

Of the three samples of cement made up from these materials and tested as below (Table 170), Cements A and B were made by mixing Marl 1 and clay in different proportions, while Cement C was made from a mixture of Marl 2 and the same clay.

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* Journ. Amer. Chem. Soc., vol. 25, p. 1200. 1903.

TABLE 169.

ANALYSES OF RAW MATERIALS CONTAINING PHOSPHORIC ACID.

	Marl 1.	Marl 2.	Clay.
Silica (SiO_2)	9.02	9.99	38.96
Alumina (Al_2O_3)	3.88*	2.05	22.60
Iron oxide (Fe_2O_3)	1.10	1.20	5.82
Lime (CaO)	45.78	45.82	16.44
Magnesia (MgO)	0.75	0.80	0.32
Volatile (CO_2, etc.)	38.87	37.99	16.02
Phosphorus pentoxide (P_2O_5)	....	1.23	

* Including about 1 per cent P_2O_5.

TABLE 170.

TESTS OF CEMENTS CONTAINING PHOSPHORIC ACID.

	Cement A.	Cement B.	Cement C.
Composition: Silica (SiO_2)	22.20	21.87	24.26
Alumina (Al_2O_3)	10.23†	6.84	7.97
Iron oxide (Fe_2O_3)	2.64	2.60	3.22
Lime (CaO)	63.83	64.85	58.74
Magnesia (MgO)	1.11	1.30	1.21
Phosphorus pentoxide (P_2O_5)	See Al_2O_3	2.50	3.82
Per cent plaster added	1½%	2%	1½%
Fineness: Passing 50-mesh sieve	100.0	100.0	100.0
“ 100- “ “	96.3	98.8	94.0
“ 200- “ “	76.0	80.0	71.0
Setting time: initial	1 hr. 10 min.	1 hr. 25 min.	12 min.
final	5 hrs. 0 min.	7 hrs. 10 min.	18 min.
Tensile strength: neat, 1 day	56 lbs.	49 lbs.	173 lbs.
“ 7 days	510 “	531 “	213 “
“ 28 “	754 “	754 “	340 “
1:3, 7 “	180 “	166 “	72 “
“ 28 “	327 “	280 “	80 “

† Including about 2 per cent P_2O_5.

Influence of intentionally added fluxes.—At a number of plants working on materials or mixtures which are naturally difficult to fuse, experiments have been made on the reduction of the clinkering temperature by the addition of fluxing materials. Experiments of this kind are usually taken up in the early stages of the manufacturer's experience. They rarely outlast the first year of actual practice, because he then begins to realize that it is difficult enough to secure a homogeneous and uniform mixture of two ingredients without going to the extra trouble of adding a third material. Occasionally, however, the fluxing mania persists, and in a few rare cases it may be entirely justifiable.

Fluorspar, sodium carbonate, and other alkali salts are the favorite materials for use as fluxes. It is certainly true that the addition of a very small percentage of some of these salts will decrease materially the difficulty of clinkering a cement mixture. Any other effect they may have on the cement, however, is either negatively or positively harmful; and in all cases their use can be avoided and equally good burning results obtained by a slightly increased fineness of grinding of the raw materials.

The direct addition of iron oxide as a flux, a practice which is followed by at least one large American plant, is somewhat different from the use of fluorspar or alkalies. The iron oxide decreases the clinkering temperature very materially and gives a slower setting product than would an equal percentage of alumina. Adding it separately to the mixture is, however, a difficult matter to arrange. The more natural course to pursue would be to look for another source of clay supply, attempting to find a clay sufficiently high in iron to obviate the necessity for adding iron oxide separately.

Calculating Mixtures of Untried Materials.

When absolutely untried raw materials are being tested for the first time, the experimental mixture must be solely on the basis of their analyses, as developed in the formula given below or in some similar device. After the plant has once started, more empirical methods of calculating the mix are used, as set forth in a later section (pp. 393–394).

Cementation Index.—Recalling the discussion on page 383 of the theoretical constitution of Portland cement, it is evident that the ideal cement (and therefore the cement mixture) should contain its various ingredients in such percentages that the following compounds can be formed: $3CaO$, SiO_2, $2CaO.Al_2O_3$, $2CaO.Fe_2O_3$, $3MgO.SiO_2$, $2MgO.Al_2O_3$, $2MgO.Fe_2O_3$. These conditions are satisfied if the formula below, called for convenience the Cementation Index, gives a value of *unity*. In this formula the chemical equivalents above noted have been changed into percentages.

$$\frac{(2.8\times\text{percentage silica } (SiO_2)\,)+(1.1\times\text{percentage alumina, } Al_2O_3)+(.7\times\text{percentage iron oxide, } Fe_2O_3)}{(\text{Percentage lime, } CaO)+(1.4\times\text{percentage magnesia, } MgO)}.$$

When the value given by this formula falls below 1.0 the cement must necessarily contain free lime or free magnesia; when it rises above 1.0, the cement must necessarily be lower in lime than is theoretically possible. The aim of the manufacturer, therefore, is to get a cement whose Cementation Index is on the safe side (i.e., over 1.0), but not too much so.

Use of the formula in proportioning mixtures.—The use of a similar formula in calculating mixtures to be made from untried materials has been well described by Prof. Newberry. The discussion here presented differs from his only in the fact that the magnesia and iron are allowed for, a correction which now seems necessary.

Following this rule, the various steps in the proportioning of a cement mixture are given below in sufficient detail to be readily followed.

Operation 1. Multiply the percentage of silica in the clayey material by 2.8, the percentage of alumina by 1.1, and the percentage of iron oxide by 0.7; add the products; subtract from the sum thus obtained the percentage of lime oxide in the clayey material plus 1.4 times the percentage of magnesia and call the result *n*.

Operation 2. Multiply the percentage of silica in the calcareous material by 2.8, the percentage of alumina by 1.1, and the percentage of iron oxide by 0.7; add the products and subtract the sum *from* the percentage of lime oxide plus 1.4 times the percentage of magnesia in the calcareous material, calling the result *m*.

Operation 3. Divide *n* by *m*. *The quotient will be the number of parts of calcareous material required for one part of clayey material.*

Example. Assuming that materials of the following composition are in use the operation would be as follows:

	Clay.	Limestone.
Silica (SiO_2)	62.2	2.4
Alumina (Al_2O_3)	16.1	2.0
Iron oxide (Fe_2O_3)	4.2	0.3
Lime (CaO)	1.6	50.2
Magnesia (MgO)	1.2	1.5
Sulphur trioxide (SO_3)	1.7	0.6
Alkalies (K_2O,Na_2O)	0.8	0.4
Water, carbon dioxide, etc.	12.2	42.6

Operation (1). Clay.

$$\begin{array}{lr}
\text{Silica} \quad \times 2.8 = 62.2 \times 2.8 = & 174.16 \\
\text{Alumina} \quad \times 1.1 = 16.1 \times 1.1 = & 17.71 \\
\text{Iron oxide} \quad \times 0.7 = 4.2 \times 0.7 = & 2.94 \\
\hline
 & 194.81 \\
\text{Lime} \quad \times 1.0 = 1.6 \times 1.0 = & 1.6 \\
\text{Magnesia} \quad \times 1.4 = 1.2 \times 1.4 = & 1.68 \\
\hline
 & 3.28
\end{array}$$

$$194.81 - 3.28 = 191.53 = n.$$

Operation (2). Limestone.

$$\begin{array}{lr}
\text{Silica} & \times 2.8 = 2.4 \times 2.8 = \ \ 6.72 \\
\text{Alumina} & \times 1.1 = \ 2.0 \times 1.1 = \ \ 2.20 \\
\text{Iron oxide} & \times 0.7 = \ 0.3 \times 0.7 = \ \ \underline{0.21} \\
 & 9.13 \\
\text{Lime} & \times 1.0 = 50.2 \times 1.0 = 50.2 \\
\text{Magnesia} & \times 1.4 = \ 1.5 \times 1.4 = \ \ \underline{2.10} \\
 & 52.30
\end{array}$$

$$52.30 - 9.13 = 43.17 = m.$$

Operation (3).

$\frac{n}{m} = \frac{191.53}{43.17} = 4.44 =$ parts of limestone to be used for each part of clay, by weight.

It must be recollected that the value given by the above formula represents the highest amount of lime theoretically possible under the best possible conditions of fine grinding and thorough burning. Even in the best-run plants these conditions cannot be attained in practice, and in a trial run either in a test kiln or in an actual plant it is foolish to attempt to reach this limit. The limestone shown by the formula should therefore be reduced in order to get safe results. A reduction of 10 per cent will probably be satisfactory. In the example given above this would work out as follows:

4.44 = parts limestone (to 1 of clay) allowed by formula
0.44 = 10% reduction for safety
4.00 = parts limestone (to 1 of clay) to be actually used

Calculating Mixtures in Current Work.

After a plant has once gotten into good working order, and as long as the same raw materials are in use, the calculation of the mix becomes a much simpler affair. Two general methods are in use:

At most plants the percentage of carbonates in the mix is made the criterion. If good results have been attained with mixtures carrying 78 to 80 per cent total carbonates ($CaCO_3 + MgCO_3$), the aim of the chemist is simply to keep the mix within these limits. The calculation in this case is simply a matter of arithmetic which does not require explanation. The other method is to keep a fixed ratio between the total insoluble matter and the total carbonates. This ratio will naturally be different at each plant, but will always be fairly constant at any one plant.

In a well-known and admirably managed marl-plant the marl is analyzed after being pumped into tanks at the mills, and the clay on its arrival at the mill. Four determinations are made on each sample of marl and three on the clay. These are:

Marl. 1. Percentage of water;
2. Weight per cubic foot;
3. Percentage of insoluble matter;
4. Percentage of carbonates.
Clay. 1. Percentage of water;
2. Percentage of insoluble matter;
3. Percentage of carbonates.

From these determinations the mix is proportioned in such a way that the ratio

$$\frac{\text{Carbonates}}{\text{Insoluble matter}}$$

shall fall within certain numerical limits. At the plant in question, which runs a high-testing cement which is also very high in silica, the above formula is made to give a value of 4.2. In the majority of plants it would fall about 3.0 to 3.4.

Composition of mixture.—The cement mixture ready for burning will commonly contain from 74 to 77.5 per cent of lime carbonate, or an equivalent proportion of lime oxide. Several analyses of actual cement mixtures are given in the following table. The ratio of silica to alumina plus iron for ordinary purposes should be about 3:1, for the cement becomes quicker setting and lower in ultimate strength as the percentage of alumina increases. If the alumina percentage be carried too high, moreover, the mixture will give a fusible, sticky clinker when burned, causing trouble in the kilns.

TABLE 171.

COMPOSITION OF ACTUAL MIXES.

Silica (SiO_2)	14.77	12.85	15.18	11.8	13.52
Alumina (Al_2O_3)	4.35	4.92	6.42	8.2	6.56
Iron oxide (Fe_2O_3)		1.21			
Lime (CaO)	43.03	42.76	42.97	41.8	42.07
Magnesia (MgO)	1.74	1.02	n. d.	0.8	2.07
Carbon dioxide (CO_2)	35.61	34.71	n. d.	n. d.	35.31
Water	n. d.	n. d.	n. d.	n. d.	n. d.

Silica (SiO_2)	13.46	13.85	12.62	14.94	12.92
Alumina Al_2O_3)	n. d.	7.20	6.00	2.66	4.83
Iron oxide (Fe_2O_3)	n. d.			1.10	1.77
Lime (CaO)	41.25	41.40	42.26	42.34	42.30
Magnesia (MgO)	n. d.	n. d.	2.67	2.21	2.08
Carbon dioxide (CO_2)	34.86	36.42	36.10	35.68	35.49
Water			n. d.	n. d.	n. d.

Methods of control.—The chemist having determined the standard of composition which he wishes to maintain in the mix, several different methods of maintaining this standard are possible. Theoretically, of course, the best of these methods is:

(1) Both raw materials are analyzed as they arrive at the mill; the mix is made according to these analyses; after grinding the mix is analyzed as a check, and if seriously incorrect is corrected by the addition of the necessary ingredients. This method is actually practiced at some plants, but in general one or the other of its two elements is gradually dropped out, so that most plants approach one of the two following extremes in practice.

(2) The raw materials are analyzed, either by borings in the quarry or by an arrival at the mill, and the mix made in accordance with these analyses. The mix may be analyzed occasionally as a check, but no serious attempt is made to correct it. In this method the entire reliance is placed on the analyses of the raw materials. With hard, dry, raw materials varying little in composition the plan works well. In dealing with marls, etc., the third plan is most used.

(3) The raw materials are mixed without analysis in approximately correct proportions, according to previous experience, and the ground mix is analyzed and brought up to proper composition (standardized) by the addition of whichever raw material proves to be deficient. In this method the correction of the mix is a regular part of the procedure. For convenience the mix is usually made always a little low in the same constituent, so that only one tank or bin of raw material needs to be kept on hand for standardizing. The following blank order shows how this is arranged in actual practice under the chemist's direction:

CLAY ORDER.

Date..................
Tank No. ....requires one hopper
of clay for each..............................
inches of marl.
Slurry tank No. ....
....
....
....
....

Changes in Composition During Manufacture.

In theory the cement produced should correspond in composition to the mixture from which it is made. In practice it is found that, in addition to the expected loss of water, carbon dioxide, and other volatile components, the cement has suffered other changes which prevent it from having the exact composition calculated from the mixture. During the process of burning, the clinker has taken up a certain amount of material from the fuel ashes, the kiln linings, or the gases produced in the kiln. The changes in composition thus caused will be briefly discussed.

The change in composition during burning is almost inevitably in the direction of raising the Cementation Index of the cement, i.e., making it more clayey. This is due to the fact that the impurities picked up during burning are all of a clayey character, the kiln linings and the fuel ash being predominantly composed of silica and alumina. To partly counterbalance these additions of clayey matter, it is probable that the dust blown out of the kiln is more clayey than the rest of the mix; but this is not sufficient in amount to avail much against the combined influence of the fuel ash and the kiln lining. Of the two factors the fuel ash is by far the most important, because the kiln bricks are pretty steadily covered by a skin of clinker.

The variation in composition of the ash derived from different types of fuel is shown by the following analyses made by Candlot.*

TABLE 172.

ANALYSES OF FUEL ASH.

	Composition of Ash from	
	Anthracite.	Gas Coke.
SiO_2	40.10	29.30
Al_2O_3	42.80	19.63
Fe_2O_3	4.70	14.64
CaO	8.10	10.64
MgO	0.90	2.70
SO_3	1.23	13.72

The differences between the calculated and actual compositions of a cement are well illustrated by the example given below. In this case a marl and clay of determined composition were mixed in a known ratio. The composition which a cement made from this mixture *should* show was calculated and is given in column 3, while the composition of the cement actually resulting is given in column 4. For these data the writer is indebted to Prof. S. B. Newberry, who carried out the test in question.

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* Bonnami. Fabrication et Controle des Chaux Hydrauliques et des Ciments, p. 58.

TABLE 173.

CHANGE IN COMPOSITION DURING BURNING.

	Raw Materials.		Finished Product.	
	Marl.	Clay.	Calculated.	Actual
Silica (SiO_2)	1.16	57.08	22.20	22.42
Alumina (Al_2O_3)	0.75	10.01	5.02	5.68
Iron oxide (Fe_2O_3)	0.75	5.37	2.85	3.22
Lime (CaO)	49.44	8.32	65.79	62.24
Magnesia (MgO)	2.04	5.22	4.06	3.22
Loss (H_2O,CO_2, etc.)	46.40	14.00	n. d.	n. d
Cementation Index	.....	.....	0.974	1.068

This point is also illustrated by the following analyses of raw mix and cement from the Syracuse plant, analyzed by Hillebrand.*

TABLE 174.

CEMENT MIXTURE AND CEMENT, SANDUSKY.

	Mix.	Cement.
Silica (SiO_2)	13.51	21.93
Alumina (Al_2O_3)	3.32	5.68
Titanic oxide (TiO_2)	0.18	0.31
Iron oxide (Fe_2O_3)	1.43	2.35
Lime (CaO)	40.84	62.92
Magnesia (MgO)	0.75	1.10
Potash (K_2O)	0.79	0.61
Soda (Na_2O)	0.22	0.29
Sulphur (S)	0.16	0.09
Sulphur trioxide (SO_3)	1.43	1.53
Carbon dioxide (CO_2)	n. d.	1.73
Water	4.20	1.40
Cementation Index	1.014	1.075

It will be seen that in both these experiments the Cementation Index of the cement has been raised considerably by the amount of silica and alumina taken up during calcination.

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* Jour. Amer. Chem. Soc., vol. 25, p. 1186. 1903.

addition to the expected loss of water, carbon dioxide, and other volatile components, the cement has suffered other changes which prevent it from having the exact composition calculated from the mixture. During the process of burning, the clinker has taken up a certain amount of material from the fuel ashes, the kiln linings, or the gases produced in the kiln. The changes in composition thus caused will be briefly discussed.

The change in composition during burning is almost inevitably in the direction of raising the Cementation Index of the cement, i.e., making it more clayey. This is due to the fact that the impurities picked up during burning are all of a clayey character, the kiln linings and the fuel ash being predominantly composed of silica and alumina. To partly counterbalance these additions of clayey matter, it is probable that the dust blown out of the kiln is more clayey than the rest of the mix; but this is not sufficient in amount to avail much against the combined influence of the fuel ash and the kiln lining. Of the two factors the fuel ash is by far the most important, because the kiln bricks are pretty steadily covered by a skin of clinker.

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Fe_2O_3	4.70	14.64
CaO	8.10	10.64
MgO	0.90	2.70
SO_3	1.23	13.72

The differences between the calculated and actual compositions of a cement are well illustrated by the example given below. In this case a marl and clay of determined composition were mixed in a known ratio. The composition which a cement made from this mixture *should* show was calculated and is given in column 3, while the composition of the cement actually resulting is given in column 4. For these data the writer is indebted to Prof. S. B. Newberry, who carried out the test in question.

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Alumina (Al_2O_3)	0.75	10.01	5.02	5.68
Iron oxide (Fe_2O_3)	0.75	5.37	2.85	3.22
Lime (CaO)	49.44	8.32	65.79	62.24
Magnesia (MgO)	2.04	5.22	4.06	3.22
Loss (H_2O,CO_2, etc.)	46.40	14.00	n. d.	n. d
Cementation Index	.....	.....	0.974	1.068

This point is also illustrated by the following analyses of raw mix and cement from the Syracuse plant, analyzed by Hillebrand.*

Table 174.

Cement Mixture and Cement, Sandusky.

	Mix.	Cement.
Silica (SiO_2)	13.51	21.93
Alumina (Al_2O_3)	3.32	5.68
Titanic oxide (TiO_2)	0.18	0.31
Iron oxide (Fe_2O_3)	1.43	2.35
Lime (CaO)	40.84	62.92
Magnesia (MgO)	0.75	1.10
Potash (K_2O)	0.79	0.61
Soda (Na_2O)	0.22	0.29
Sulphur (S)	0.16	0.09
Sulphur trioxide (SO_3)	1.43	1.53
Carbon dioxide (CO_2)	n. d.	1.73
Water	4.20	1.40
Cementation Index	1.014	1.075

It will be seen that in both these experiments the Cementation Index of the cement has been raised considerably by the amount of silica and alumina taken up during calcination.

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* Jour. Amer. Chem. Soc., vol. 25, p. 1186. 1903.

30 per cent in fresh clays. The chemically combined water will depend largely on the composition of the clay, and may vary from 5 to 12 per cent. The hygroscopic or mechanically held water of clays can be driven off at a temperature of 212° F., while the chemically combined water is lost only at a low red heat. The total water, therefore, to be driven off from clays may range from 6 to 42 per cent, depending on the weather, the drainage of the clay-pit, and the care taken in preventing unnecessary exposure to moisture of the excavated clay. The average total amount of moisture will probably be about 15 per cent.

In dealing with shales, the mechanically held water will rarely rise above 10 per cent, and can commonly be kept well below that limit. An additional 2 to 7 per cent of water will be carried by any shale in a state of chemical combination.

At a few plants marl is used with clay in a dry process. As noted elsewhere the marls as excavated carry usually about 50 per cent of water. Marl presents a more difficult problem than do the other raw materials, because the vegetable matter usually present in marls is extremely retentive of water.

It will be seen, therefore, that cement materials may carry from 1 per cent to 50 per cent of water when they reach the mill. The average throughout the country would probably fall close to 5 per cent if the marls are excluded. In a dry process it is necessary to remove practically all of this water before commencing the grinding of the materials. One reason for this is that fine pulverizing cannot be economically or satisfactorily accomplished unless absolutely dry material is fed to the grinding machinery. Another reason, which is one of convenience rather than of necessity, is that the presence of water in the raw materials complicates the control of the cement mixture.

Methods and costs of drying.—The type of dryer used at most cement-plants is a cylinder approximately 5 feet in diameter and 40 feet or so in length, set at a slight inclination to the horizontal and rotating on bearings. The wet raw material is fed in at the upper end of the cylinder, and it moves gradually toward the lower end, under the influence of gravity, as the cylinder revolves. In many dryers angle irons are bolted to the interior in such a way as to lift and drop the raw material alternately, thus exposing it more completely to the action of the heated gases and materially assisting in the drying process. The dried raw material falls from the lower end of the cylinder into an elevator boot and is then carried to the grinding-mills.

The drying-cylinder is heated either by a separate furnace or by waste gases from the cement-kilns. In either case the products of

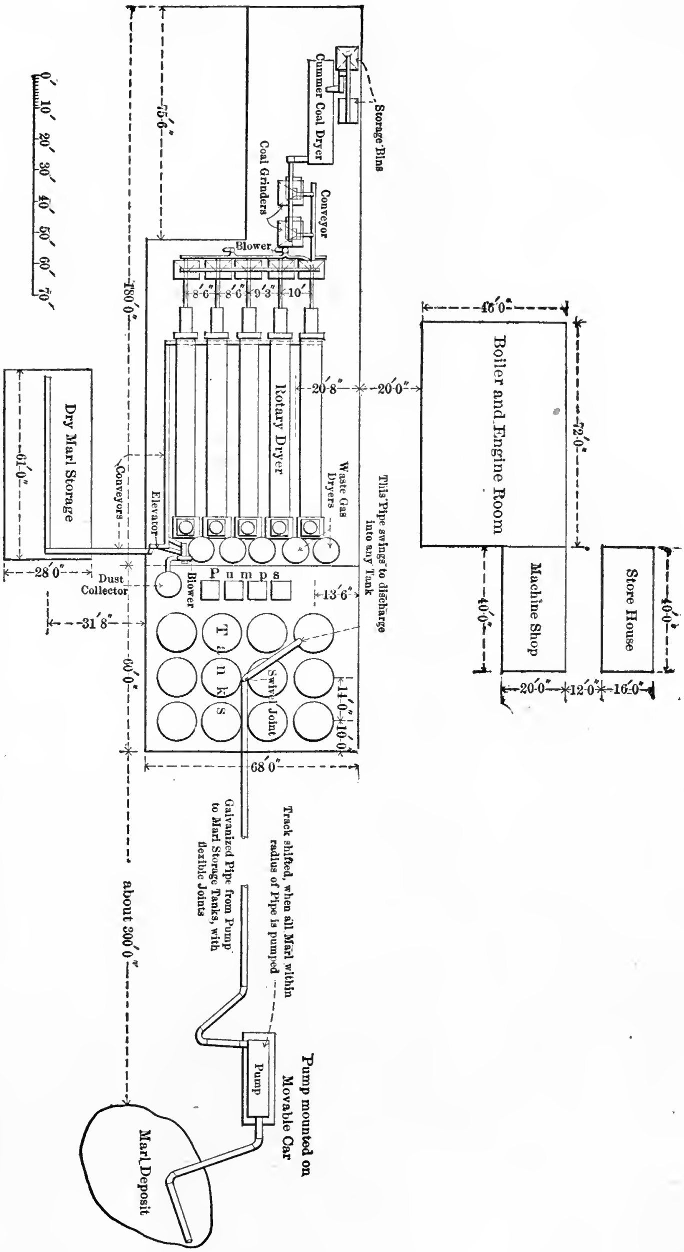

FIG. 82.—Marl-drying plant, Hecla P. C. Co. (Engineering News.)

combustion are introduced into the cylinder at its lower end, are drawn through it, and escape up a stack set at the upper end of the dryer.

The dryer above described is the simplest and is most commonly used. For handling the small percentages of water contained in most cement materials it is very efficient, but for dealing with high percentages of water, such as are encountered when marl is to be usd in a dry process, it seems probable that double-heating dryers will be found more economical.

This type is exemplified by the Ruggles-Coles dryer, a detailed description of which is given in the section on slag cements, p. 649. In this dryer a double cylinder is employed. The wet raw material is fed into the space between the inner and outer cylinders, while the heated gases pass first through the inner cylinder and then, in a reverse direction, through the space between the inner and outer cylinders. This double-heating type of dryer is employed in almost all of the slag-cement plants in the United States, and is also in use in several Portland-cement plants.

When vertical kilns were in use, drying-floors and drying-tunnels were extensively used, but at present they can be found only in a few plants, being everywhere else supplanted by the rotary dryers.

At the marl-plant of the ill-fated Hecla Portland Cement Company, which is shown in Fig. 82, rotary kilns were actually used as driers, because of the extreme difficulty encountered in properly drying this material in a drier of ordinary type.

In the Edison plant a stationary vertical tower drier is used for the cement rock and limestone.

The Edison stack drier shown in Fig. 83 is described as follows in a recent article * in the *Iron Age:* The chimney surmounting this flue is used only when starting a fire, the gases of combustion ordinarily passing directly to the dryer stack to rise through the falling stream of rock and thoroughly dry it. The baffle-plate system is such that the fall of a piece of rock from the lowest screen to the bottom of the dryer requires 26 seconds. From above the baffles near the top of the stack the gases are drawn out by an 80-inch exhaust-fan, driven by a 50-horse-power motor, and are passed through a dust-settling chamber on their way to the atmosphere. A 12-inch screw conveyor returns the collected dust to the bottom of the dryer stack and replaces it in the system. The baffle-plates of the

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* The Iron Age, Dec. 24, 1903, p. 5.

upper sections of the stack are arranged to slide longitudinally in their slots, reciprocating motion being provided by a motor-driven system of rocker arms sliding successive rows of plates in opposite directions at the rate of 20 cycles per minute. By this action clogging of possibly damp rock is prevented until it has fallen far enough to be dried sufficiently to have no such tendency. The shear-pin principle, used at this plant for driving the crushing rolls, is also applied in a modified form to the baffle-shakers. The rock-dryer is 8×8 feet in plan section, 40 feet high, and has a capacity of 3000 tons per day, the same as the crusher plant. The performance of the dryer stack is very efficient; the fuel consumption is small, the percentage of moisture in the crushed rock is reduced from 3 or 4 per cent to within 1 per cent, and the gases leave at a temperature scarcely above 212°. A blower equipment is provided for increasing the furnace draft when necessary.

The cost of drying raw materials will depend on the cost of fuels, the percentage of water present in the wet material, and the efficiency of the dryer. Dryers are usually arranged and located so as to require little attention, and the labor costs of drying are therefore slight. Even under the most unfavorable conditions 5 lbs. of water can be expected to be evaporated for each pound of coal used, while a good dryer will usually evaporate 7 or 8 lbs. of water per pound of coal. Marls containing much organic matter are notably more retentive of moisture than any other raw material, and a marl-drying proposition is therefore apt to be expensive. For a full description of a most elaborate and

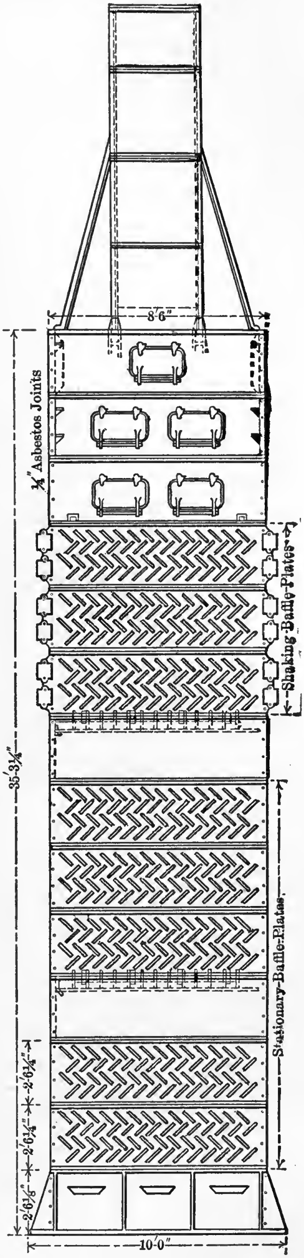

FIG. 83.—Elevation of stack drier, Edison plant. (Engineering News.)

unsuccessful installation for marl-drying, reference should be made to the paper cited below.*

Grinding and Mixing.

Part at least of the reduction is usually accomplished before the materials are dried, but for convenience the subjects have been separated in the present chapter.

General methods.—Usually the limestone or cement rock is passed through a crusher at the quarry or mill before being sent to the drier; and occasionally one or both of the raw materials is still further reduced before grinding, but the principal part of the grinding process always takes place after the material has been dried.

After drying, the two raw materials may either be mixed immediately or each may be separately reduced before mixing. Automatic mixers, of which many slightly different types are in use, give a mixture in the proportions determined upon by the chemist.

The further reduction of the mixture is usually carried on in two stages, the material being ground to, say, 30-mesh in a ball mill, kominuter, Griffin mill, etc., and finally reduced in a tube mill. At a few plants, however, single-stage reduction is practiced in Griffin or Huntington mills, while at the Edison plant at Stewartsville, N. J., the reduction is accomplished in a series of rolls.

The majority of plants use either the Griffin mill and tube mill or the ball mill and tube mill; and there is probably little difference in the total cost of operating these two combinations. The former combination (Griffin + tube) is commonly considered to require less power, but more repairs than the latter; but even this can hardly be regarded as an established fact. The ball mill has never been quite as much of a success as its companion, the tube mill, and has been replaced at a number of plants by the kominuter.

Plans of actual plants.—Plans of several actual plants have been inserted for the purpose of illustrating the brief statement made above.

The plant of the Lawrence Cement Company, of Siegfried, Pa., published by courtesy of Messrs. Lathbury and Spackman, is given in Fig. 85. The materials used here are cement rock and limestone. These are separately crushed in Gates crushers and dried in rotary driers, after which they are mixed and reduced in Williams mills and tube mills.

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* Plant and buildings of the Hecla Portland Cement and Coal Co. Engineering News, vol. 51, pp. 243–245. 1904.

In Fig. 84 the raw side of an ideal mill is presented, showing a very compactly installed layout of kominuters and tube mills for an output of 3500 barrels per day.

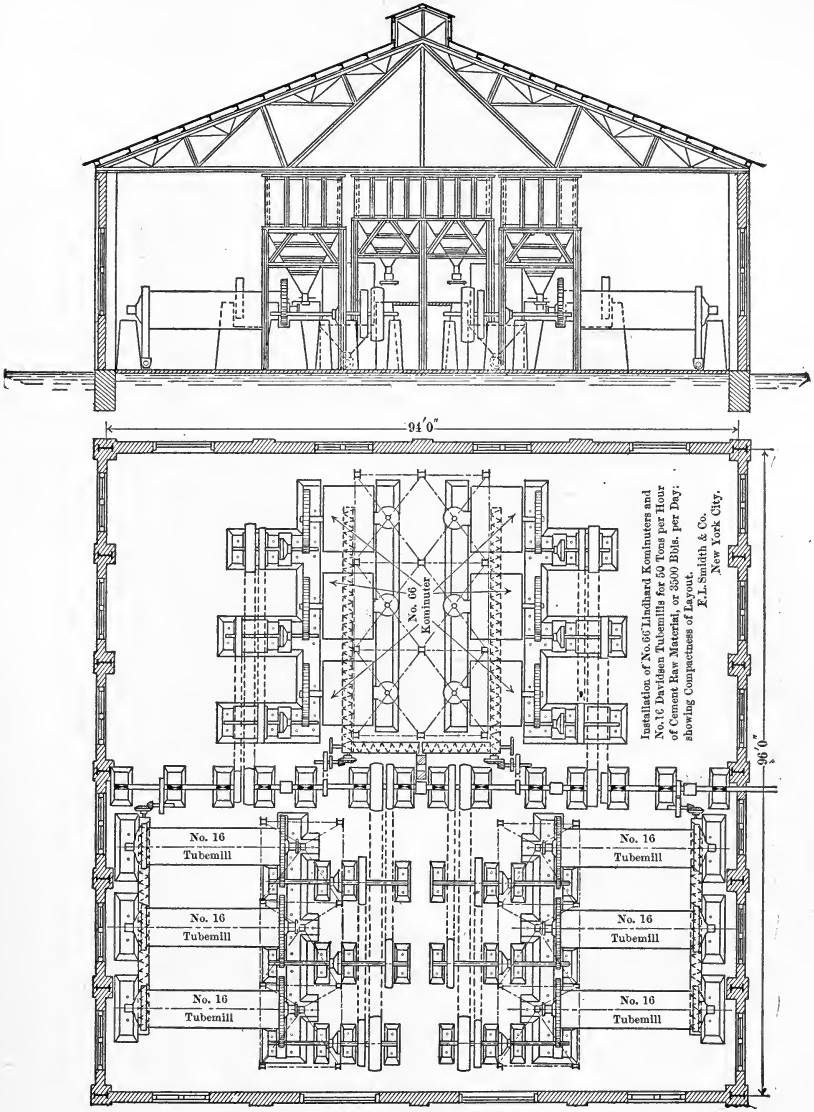

FIG. 84.—Installation of kominuters and tube mills.

The plant of the Hudson P. C. Co., a typical modern dry-process plant, is shown in Fig. 86, reproduced by courtesy of *Engineering News.*

In the article * accompanying this figure, the raw side of the mill is described as follows:

"Following the course of the material step by step, it will be seen that the loaded cars from the quarry come into the mill at the east end at an elevation of 12 feet above the crusher-room floor, which is itself elevated $13\frac{1}{2}$ feet above the main mill floor, and that they dump through the track onto the crusher-room floor. Flush with this floor are the tops of three rotary crushers, two for crushing limestone and one for crushing shale. The two limestone crushers are run by a 45-H.P. electric motor and the shale crusher by a 22-H.P. electric motor. From the crushers the stone is delivered, shale and limestone separately, into four rotary driers, each of which is operated by a 5-H.P. electric motor. From the driers the stone passes separately to the ball mills for the first grinding. These ball mills are of the Krupp type, and there are five of them, each operated by a 50-H.P. electric motor. From the ball

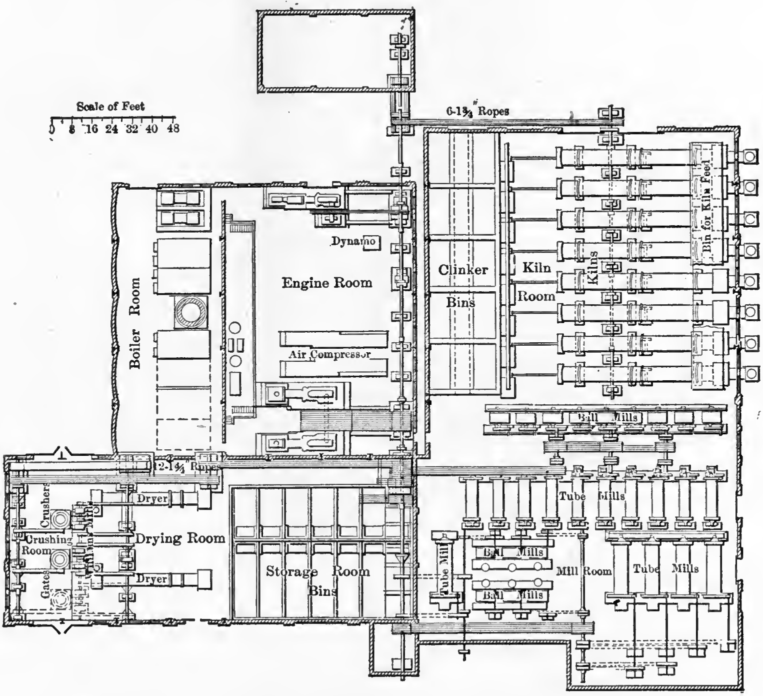

FIG. 85.—Plan of plant, Lawrence Cement Co., Siegfried, Pa. (Lathbury and Spackman.)

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* Engineering News, vol. 50, pp. 70, 71. July 23, 1903.

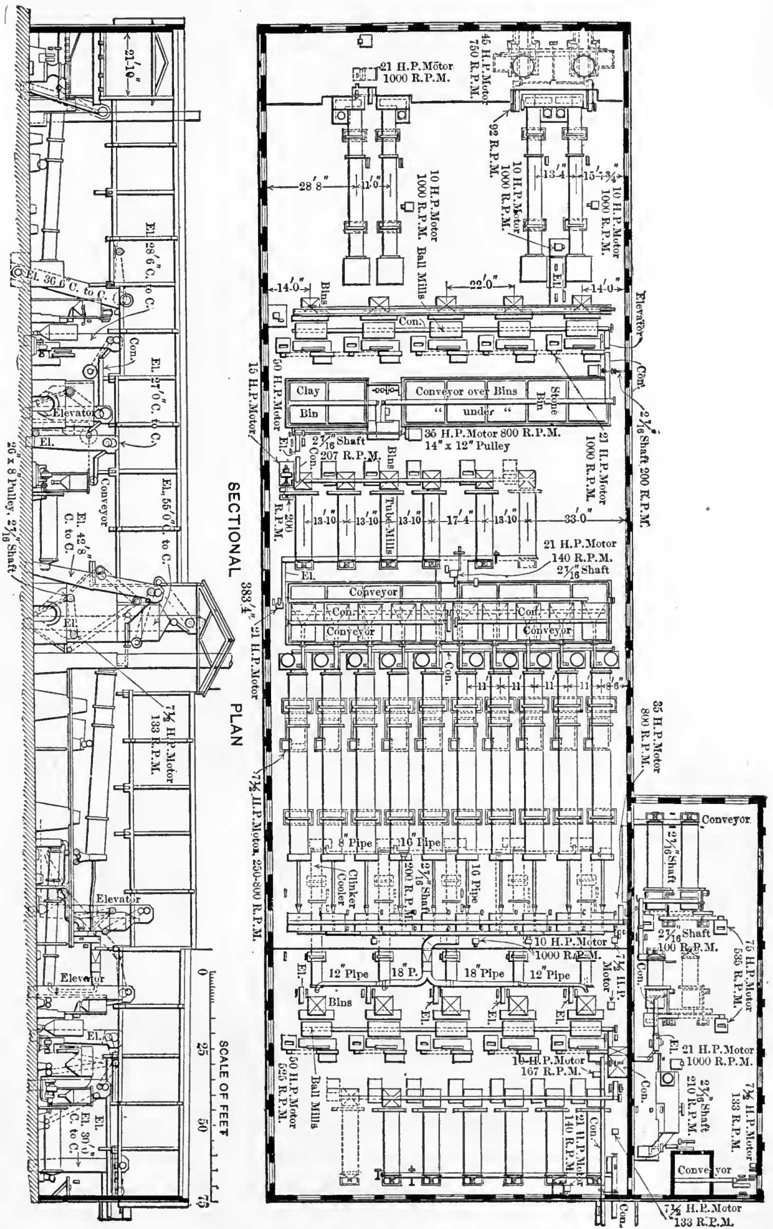

FIG. 86.—Plan of plant, Hudson P. C. Co., Hudson, N. Y. (Engineering News.)

mills the shale powder is delivered to a set of two bins and the limestone powder to a set of five bins. These bins are so constructed as to discharge automatically into a double elevator, whence the materials are discharged into a double hopper over a tandem automatic weighing-machine, which weighs out the proper proportion of each material. The two products are then mixed thoroughly by being conveyed together by elevator *E* and conveyors $9\frac{1}{2}$ and 9 to the steel bins feeding the tube mills. There are six of these tube mills and they are driven in groups by a 75-H.P. electric motor.

"The tube-mill discharges feed onto a screw conveyor 10, thence to the elevator *EE*, and thence to screw conveyor 11, which discharges into two groups of stock bins. Screw conveyors 13 running underneath these bins take the material right and left to the elevator *F*, which feeds the right and left screw conveyors 12 that discharge into the kiln feed bins. There are ten of these bins and each one feeds one rotary kiln."

Actual Equipments of Dry-process Plants.

The present-day practice in dry-process plants is shown better by the following data on the actual equipments of a number of these plants than by any amount of general statements on the subject. Reference should also be made to Chapter XXXI, where general crushing practice is discussed.

Plant No. 1. Uses limestone and shale.

Limestone	Shale
1 Gates crusher	1 Gates crusher

1 Mosser drier
1 kominuter
4 tube mills
4 kilns

Plant No. 2. Limestone and shale.

Limestone	Shale

1 crusher
1 rotary drier
1 Williams mill
2 tube mills
2 kilns

Plant No. 3. Limestone and shale.

Limestone	Shale
1 crusher	1 tunnel drier
1 rotary drier	1 crusher

1 dry-pan to 30-mesh
2 Raymond pulverizers
3 kilns, 50 feet

Plant No. 4. Limestone and shale.

Limestone	Shale
2 Alton crushers	1 dry-pan to 8-mesh
1 Bonnot drier	1 rotary drier
10 sets rolls	2 tube mills
9 sets Sturtevant emery mills	

4 intermittent tube mills
4 kilns

Plant No. 5. Uses fairly hard limestone, with shale.

Limestone	Shale
1 Gates crusher, coarse rock sold; screenings used in cement plant	1 disintegrator
2 Bonnot rotary driers	2 Bonnot rotary driers

3 kominuters to 20-mesh
4 tube mills to 92% through 100-mesh
8 kilns

Plant No. 6. Limestone and shale.

Limestone	Shale
1 Gates crusher	1 Gates crusher

1 rotary drier
3 ball mills
4 tube mills
6 kilns

Plant No. 7. Uses hard limestone and shale.

Limestone	Shale
2 Austin crushers	1 Sturtevant crusher
2 Bonnot driers	2 Bonnot driers
2 Krupp ball mills	1 Bonnot ball mill

5 tube mills
10 kilns

Plant No. 8. Limestone and shale.

Limestone	Shale

1 Gates crusher, No. 5
1 rotary drier
3 Williams mills
3 tube mills
6 kilns

Plant No. 9. Limestone and shale.

Limestone	Shale

2 crushers
2 rotary driers
4 ball mills
6 tube mills
8 kilns

Plant No. 10. Limestone and cement rock.

Limestone	Cement rock

2 crushers
2 rotary driers
6 ball mills
6 tube mills
10 kilns

Plant No. 11. Limestone and shale.

Limestone	Shale
1 crusher	1 disintegrator
1 rotary drier	1 rotary drier

2 kominuters
2 Davidsen tube mills
6 kilns, 60 feet

Plant No. 12. Uses marl and clay in a dry process.

Marl	Clay
1 rotary drier	1 rotary drier

2 tube mills
3 kilns

List of references on dry-process plants and methods.—The following papers describe plants using the dry process or details connected with that process.

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Meade, R. K. The plant of the Northampton Portland Cement Co., Pa. Engineering Record, vol. 48, pp. 182, 183. Dec. 5, 1903.

Meyer, H. C. New works of the Coplay Cement Co., Coplay, Pa. Engineering Record, Feb. 27, 1900. Cement Industry, pp. 69–77. 1900.

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Vredenburgh, W. The Virginia Portland Cement Co.'s Works, Craigsville, Va. Engineering Record, July 28, 1900. Cement Industry, pp. 132–141. 1900.

Anon. The Almendares Portland Cement Works, Cuba. Engineering Record. vol. 49, pp. 36–38. Jan. 9, 1904.

Anon. Edison Portland Cement Company [N. J.]. Iron Age, Dec. 24, 1903.

Anon. The works of the Edison Portland Cement Co., near Stewartsville, N. J. Engineering Record, vol. 48, pp. 796–802. Dec. 26, 1903.

Anon. The Edison Portland Cement Works at New Village, N. J. Engineering News, vol. 50, pp. 555–559. 1903.

Anon. Alsen's American Portland Cement Works, N. Y. Engineering Record, vol. 47, pp. 10–13. Jan. 3, 1903.

Anon. Plant of the Hudson Portland Cement Co., at Hudson, N. Y. Engineering News, vol. 50, pp. 70–71. July 23, 1903.

(2) Methods Used with Slag-Limestone Mixtures.

While the manufacture of Portland cement from a mixture of slag and limestone is similar in general theory and practice to its manufacture from a limestone-clay or other dry raw materials, certain interesting differences occur in the preparation of the mixture. In the following paragraphs the general methods of preparing mixtures of slag and limestone for use in Portland-cement manufacture will first be noted, after which certain processes peculiar to the use of this particular mixture will be described separately.

General methods.—After it had been determined that the puzzolan cement made * by mixing slag with lime without subsequent burning of the mixture was not an entirely satisfactory structural material, attention was soon directed toward the problem of making a true Portland cement from such slag. The blast-furnace slags commonly available, while carrying enough silica and alumina for a cement mixture, are too low in lime to be suitable for Portland cement. Addi-

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*See Part VII.

tional lime must be added, usually in the form of limestone, the slag and limestone must be well mixed and the mixture properly burned. The general methods for accomplishing the proper mixture of the materials vary in details. It seems probable that the first method used in attempting to make a true Portland cement from slag was to dump the proper proportion of limestone, broken into small lumps, into molten slag. The idea was that both mixing and calcination could thus be accomplished in one stage; but in practice it was found that the resulting cement was variable in composition and always low in grade. This method has accordingly fallen into disuse, and at present three different general processes of preparing the mixture are practiced at different European and American plants.

1. The slag is granulated, dried, and ground, while the limestone is dried and ground separately. The two materials are then mixed in proper proportions, the mixture is finely pulverized in tube mills, and the product is fed in a powdered state to rotary kilns.

2. The slag is granulated, dried, and mixed with slightly less than the calculated proper amount of limestone, which has been previously dried and powdered. To this mixture is added sufficient powdered slaked lime (say 2 to 6 per cent) to bring the mixture up to correct composition. The intimate mixture and final reduction are then accomplished in ball and tube mills. About 8 per cent of water is then added, and the slurry is made into bricks, which are dried and burned in a dome or chamber kiln.

3. Slag is granulated and mixed, while still wet, with crushed limestone in proper proportions. This mixture is run through a rotary calciner, heated by waste kiln gases, in which the temperature is sufficient not only to dry the mixture but also to partly powder it and to reduce most of the limestone to quicklime. The mixture is then pulverized and fed into rotary kilns.

Of the three general processes above described the second is unsuited to American conditions. The first and third are adapted to the use of the rotary kiln. The third seems to be the most economical, and has given remarkably low fuel consumption in practice, but so far has not been taken up in the United States.

Certain points of manufacture peculiar to the use of mixtures of slag and limestone will now be described.

Composition of the slag.—The slags available for use in Portland-cement manufacture are of quite common occurrence in iron-producing districts. Those best suited for such use are the more basic blast-furnace slags, and the higher such slags run in lime the more available they are for this use. The slags utilized will generally run from 30 to 40 per cent lime. The presence of over 3 per cent or so of magnesia in a slag is, of course, enough to render its use as a Portland-cement material inadvisable; and on this account slags from furnaces using dolomite (magnesian limestone) as a flux are unsuited for cement-manufacture. The presence of any notable percentage of sulphur is also a drawback, though, as will be later noted, part of the sulphur in the slag will be removed during the processes of manufacture.

Granulation of slag.—If slag be allowed to cool slowly, it solidifies into a dense, tough material, which is not readily reduced to the requisite fineness for a cement mixture. If it be cooled suddenly, however, as by bringing the stream of molten slag into contact with cold water, the slag is "granulated", i.e., it breaks up into small porous particles. This granulated slag or "slag sand" is much more readily pulverized than a slowly cooled slag; its sudden cooling has also intensified the chemical activity of its constituents so as to give it hydraulic properties, while part of the sulphur contained in the original slag has been removed. The sole disadvantage of the process of granulating slag is that the product contains 20 to 40 per cent of water, which must be driven off before the granulated slag is sent to the grinding machinery.

In practice the granulation of the slag is effected by directing the stream of molten slag direct from the furnace into a sheet-iron trough. A small stream of water flows along this trough, the quantity and rate of flow of the water being regulated so as to give complete granulation of the slag without using an excessive amount of water. The trough may be so directed as to discharge the granulated slag into tanks or into box cars, which are usually perforated at intervals along the sides so as to allow part of the water to drain off.

Drying the slag.—As above noted, the granulated slag may carry from 20 to 40 per cent of water. This is renewed by treating the slag in rotary driers. In practice such driers give an evaporation of 8 to 10 pounds of water per pound of coal. The practice of slag-drying is very fully described in Part VII of this volume, pages 649–652, where figures and descriptions of various driers are also given, with data on their evaporative efficiency. As noted earlier in this article, one of the methods of manufacturing Portland cement from slag puts off the drying of the slag until after it has been mixed with the limestone, and then accomplishes the drying by utilizing waste heat from the kilns. Kiln gases could, of course, be used anyway in the slag-driers, but it so happens that they have not been so used except in plants following the method in question.

Grinding the slag.—Slag can be crushed with considerable ease to about 50-mesh, but notwithstanding its apparent brittleness it is difficult to grind it finer. Until the introduction of the tube mill, in fact, it was almost impossible to reduce this material to the fineness necessary for a cement mixture, and the proper grinding of the slag is still an expensive part of the process, as compared with the grinding of limestone, shales, or clay.

Composition of the limestone.—As the slag carries all the silica and alumina necessary for the cement mixture, the limestone to be added to it should be simply a pure lime carbonate. The limestone used for flux at the furnace which supplies the slag will usually be found to be of suitable composition for use in making up the cement mixture.

Economics of using slag-limestone mixtures.—The manufacture of a true Portland cement from a mixture of slag and limestone presents certain undoubted advantages over the use of any other raw materials, while it has also a few disadvantages.

Probably the most prominent of the advantages lies in the fact that the most important raw material—the slag—can usually be obtained more cheaply than an equal amount of natural raw material could be quarried or mined. The slag is a waste product, and a troublesome material to dispose of, for which reason it is obtained at small expense to the cement-plant. Another advantage is due to the occurrence of the lime in the slag as oxide, and not as carbonate. The heat necessary to drive off the carbon dioxide from an equivalent mass of limestone is therefore saved when slag forms part of the cement mixture, and very low consumption is obtained when slag-limestone mixture is burned.

Of the disadvantages, the toughness of the slag and the necessity for drying it before grinding are probably the most important. These serve to partly counterbalance the advantages noted above. A third difficulty, which is not always apparent at first, is that of securing a proper supply of suitable slag. Unless the cement-plant is closely connected in ownership with the furnaces from which its slag supply is to be obtained, this difficulty may become very serious. In a season when a good iron market exists the furnace manager will naturally give little thought to the question of supplying slag to an independent cement-plant.

The advantages of the mixture, however, seem to outweigh its disadvantages, for the manufacture of Portland cement from slag is now a large and growing industry in both Europe and America. Two Portland-cement plants using slag and limestone as raw materials have been established for some time in this country, several others are in course of construction at present, and it seems probable that in the near future Alabama will join Illinois and Pennsylvania as an important producer of Portland cement from slag.

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(The more important articles are preceded by an asterisk.)

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* Lathbury, B. B., and Spackman, H. S. The Clinton Cement Company's plant, Pittsburg, Pa. The Rotary Kiln, pp. 82–85. 1902.

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* Von Schwarz, C. The utilization of blast-furnace slag. Journ. Iron and Steel Inst., 1900, No. 1, pp. 141–152. Engineering News, Sept. 27, 1900. Engineering Record, June 2, 1900.

* Von Schwarz, C. Portland cement manufactured from blast-furnace slag. Journ. Iron and Steel Inst., 1903, No. 1, pp. 203–230.

(3) Blast-furnace Methods of Making Cement.

Attempts have been made to manufacture Portland cement by mixing the raw materials without grinding and burning the mixture to a state of complete fusion in a kiln resembling a blast-furnace in design and action. The Hurry and Seaman patents covering a method of this type are described as follows:*

Raw materials containing carbonate of lime, silica, and alumina are mixed with carbonaceous fuel, the combustion of which is supported

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* Journal Soc. Chem. Industry, vol. 21, p. 1079. 1902

by a blast of air supplied through tuyeres, and a pressure about 10 to 20 lbs. above that of the atmosphere is maintained in the furnace, whereby the materials are melted, the molten cement being afterward drawn off, cooled, and pulverized. The carbon dioxide derived from the carbonate of lime is reduced to carbonic oxide by the incandescent fuel, and in this atmosphere any oxide of iron in the raw materials is said to be reduced to metallic iron, which sinks and can thus be separated from the molten cement, whereby a superior product is obtained. The carbonate of lime may be preliminarily calcined and the carbon dioxide introduced together with air into the calcining furnace, where it is reduced and then again burned to carbon dioxide. The increased pressure is maintained either by arranging the height of the kiln so that the combustion gases formed in the lower part are prevented from escaping freely by the height of the mass of materials above or by a throttle-valve arranged in the outlet at the top of the kiln.

Von Forell has taken out foreign patents on processes of quite similar type.

(4) Wet Methods of Preparation.

Wet methods of preparing Portland-cement mixtures date back to the time when millstones and similar crude grinding contrivances were in use. With such imperfect machinery it was almost impossible to grind dry materials fine enough to give a good Portland-cement mixture. The advent of good grinding machinery has practically driven out wet methods of manufacture in this country, except in dealing with materials such as marls, which naturally carry a large percentage of water. Two plants in the United States do, it is true, deliberately add water to a limestone-clay mixture; but the effect of this practice on the cost sheets of these remarkable plants is not encouraging.

In preparing cement mixtures from marl and clay, a few plants dry both materials before mixing. It seems probable that this practice will spread, for the wet method of mixture is inherently expensive. At present, however, almost all marl-plants use wet methods of mixing, and it is therefore necessary to give some space to a discussion of such methods.

Certain points regarding the location, physical condition, and chemical composition of the marls and clays used in such mixtures have important effects upon the cost of the wet process. As regards location considered on a large scale, it must be borne in mind that marl deposits of workable size occur only in the Northern States and in Canada. In consequence the climate is unfavorable to continuous working throughout the year, for the marl is usually covered with water, and in winter it is difficult to secure the material. In a minor sense location is still an important factor, for marl deposits necessarily and invariably are found in depressions; and the mill must, therefore, just as necessarily be located at a higher level than its source of raw material, which involves increased expense in transporting the raw material to the mill.

Glacial clays, which are usually employed in connection with marl, commonly carry a much larger proportion of sand and pebbles than do the sedimentary clays of more southern regions.

The effect of the water carried by the marl has been noted in an earlier paper. The material as excavated will consist approximately of equal weights of lime carbonate and of water. This on the face of it would seem to be bad enough as a business proposition; but we find that in practice more water is often added to permit the marl to be pumped up to the mill.

On the arrival of the raw materials at the mill the clay is often dried, in order to simplify the calculation of the mixture. The reduction of the clay is commonly accomplished in a disintegrator or in edge-runner mills, after which the material is further reduced in a pug-mill, sufficient water being here added to enable it to be pumped readily. It is then ready for mixture with the marl, which at some point in its course has been screened to remove stones, wood, etc., so far as possible. The slurry is further ground in pug-mills or wet-grinding mills of the disk type, while the final reduction takes place commonly in wet-tube mills. The slurry, now containing 30 to 40 per cent of solid matter and 70 to 60 per cent of water, is pumped into storage-tanks, where it is kept in constant agitation to avoid settling. Analyses of the slurry are taken at this point, and the mixture in the tanks is corrected if found to be of unsatisfactory composition. After standardizing, the slurry is pumped into the rotary kilns. Owing to the large percentage of water contained in the slurry the fuel consumption per barrel of finished cement is 30 to 50 per cent greater and the output of each kiln correspondingly less than in the case of a dry mixture. This point will, however, be further discussed in a later chapter.

At a plant working a rather stiff slurry carrying only 40 per cent of water two Bonnot tube mills, using 25 H.P. each, handled together 4000 cubic feet of slurry in twenty-four hours, equivalent to a production of 300 or more barrels of cement per day. This is equivalent to a power consumption of a little less than 4 H.P. hours per barrel of finished cement. The clay contained in the slurry had been passed through a dry-pan and the slurry was then mixed and ground to some extent in a pug-mill.

A Bonnot 22′×5′ tube mill used at a marl-plant on not very wet slurry ground about 20 to 30 barrels per hour, taking 30 H.P. in doing so. This slurry had not been previously treated except by passing it through a stone separator, so that the total power for grinding raw material at this plant was from 1 H.P. to 1½ H.P. per barrel cement.

At another plant a Bonnot 16-foot tube mill ground 12 barrels per hour raw wet mix, taking 15 to 20 H.P. in doing so, the marl having previously been passed through a stone separator and pug-mill and the clay through dry-pans.

Other plants report slightly different results with wet-tube mills. To sum up, from all data it seems that the preparation of a wet mix in tube mills will usually require from 1 H.P. hour to 2 H.P. hours per barrel cement. The power and product, however, will vary greatly with the percentage of water in the mix, as well as with the hardness of the particular marl and clay employed.

The highest power consumption per barrel was shown by a plant which required 3.9 H.P. hours per barrel for preparing its raw materials for the kiln. The marl used at this plant is unusually hard, and the mixture is made with less water than usual. This gives a fairly high kiln efficiency (100 barrels per day per kiln with a fuel consumption of 160 lbs. coal per barrel), but it largely increases the work to be done by the grinding machinery on the raw side. Several of the grinding-mills used at this plant are, in addition, very inefficient types, and to this combination of unfavorable conditions is to be ascribed the high-power consumption on the raw side of the plant.

All of the tanks containing slurry must be provided with some appliance for agitating the mixture or otherwise the heavier portion would settle at the bottom of the tanks, leaving fairly clear water above. Three different methods of agitating are in use at various marl-plants:

1. A vertical central shaft equipped with long arms or paddles;
2. A horizontal shaft crossing the tank a little above its bottom and fitted with screw blades;
3. The injection at intervals of jets of compressed air.

Any of these three devices gives fairly good results, but none of them seems entirely satisfactory to the managers of the plants in which they are installed. The first two use an unexpectedly large amount of power.

It may be of interest, for comparison with the above description of the wet process with rotary kilns, to insert a description of the semi-wet process as carried on a few years ago at the dome-kiln plant of the Empire Portland Cement Company of Warners, N. Y. The plant has been remodeled since that date, but the processes formerly followed are still of interest, as they resulted in a high-grade, though expensive, product.

At the Empire plant the marl and clay are obtained from a swamp about three fourths of a mile from the mill. A revolving derrick with clam-shell bucket was employed for excavating the marl, while the clay was dug with shovels. The materials are taken to the works over a private narrow-gauge road, on cars carrying about three tons each, drawn by a small locomotive. At the mill the cars were hauled up an inclined track, by means of a cable and drum, to the mixing floor.

The clay was dried in three Cummer "salamander" driers, after which it was allowed to cool, and then carried to the mills. These mills were of the Sturtevant "rock-emery" type, and reduced the clay to a fine powder, in which condition it was fed, after being weighed, to the mixer. The marl was weighed and sent directly to the mixer, no preliminary treatment being necessary. The average charge was about 25 per cent clay and about 75 per cent marl.

The mixing was carried on in a mixing pan 12 feet in diameter, in which two large rolls, each about 5 feet in diameter and 16-inch face, ground and mixed the materials thoroughly. The mixture was then sampled and analyzed, after which it was carried by a belt conveyor or two pug-mills, where the mixing was completed and the slurry formed into slabs about 3 feet long and 4 to 5 inches in width and height. These on issuing from the pug-mill were cut into a number of sections, so as to give bricks about 6 inches by 4 inches by 4 inches in size. The bricks were then placed on slats, which were loaded on rack cars and run into the drying tunnels. The tunnels were heated by waste gases from the kilns and required from twenty-four to thirty-six hours to dry the bricks.

After drying, the bricks were fed into dome kilns, twenty of which were in use, being charged with alternate layers of coke and slurry bricks. The coke charge for a kiln was about four or five tons, and this produced 20 to 26 tons of clinker at each burning, thus giving a fuel consumption of about 20 per cent, as compared with the 40 per cent or so required in the rotary kilns using wet materials. From thirty-six to forty hours were required for burning the charge. After cooling, the clinker was shoveled out, picked over by hand, and reduced in a Blake crusher, Smidth ball mills, and Davidsen tube mills.

Actual Equipment of Wet-process Plants.

Plant No. 1. Uses a hard limestone and a clay in a wet process.

Limestone
2 crushers

Clay

4 ball mills
4 wet paddle mills
4 wet tube mills
10 kilns

Plant No. 2. Uses a fairly hard limestone and a shale in a wet process.

Limestone
1 Gates crusher to 3½ inches
3 small Gates crushers to ½ inch

Shale
2 Williams mills

3 rotary driers
21 Griffin mills to 90% through 100-mesh
3 pug-mills
15 slurry tanks
21 kilns

Plant No. 3. Marl and clay.

Marl

Clay
1 rotary drier
1 dry-pan

1 pug-mill, 40% water
2 Bonnot tube mills
3 kilns, 60 feet

Plant No. 4. Marl and clay.

Marl
1 stone separator

Clay
1 dry-pan

2 pug-mills
4 Bonnot tube mills
5 kilns

Plant No. 5. Marl and clay.

Marl

Clay

1 stone separator
Tanks
1 wet tube mill
Tanks
3 kilns

Plant No. 6. Marl and clay.

Marl

Clay

2 wet-pans

3 Abbie mills

2 wet ball mills
3 wet tube mills

13 kilns

Plant No. 7. Marl and shale.

Marl	Shale
1 stone separator	2 dry-pans
1 pug-mill	|

6 Bonnot tube mills, 16 feet
14 kilns

Plant No. 8. Marl and clay.

Marl	Clay
1 stone separator.	1 pug-mill

1 pug-mill
3 tube mills
6 kilns

Plant No. 9. Marl and clay.

Marl	Clay
1 stone separator	|

2 wet-pans
4 tube mills
14 kilns

Plant No. 10. Marl and clay.

Marl	Clay
1 stone separator	1 rotary drier

1 pug-mill
4 tube mills
6 kilns, 70 feet
4 kilns, 60 feet

Plant No. 11. Marl and shale.

Marl	Shale
1 stone separator	1 rotary drier
|	1 Williams mill

1 pug-mill
2 tube mills
9 kilns, 70 feet

List of references on wet-process plants and methods.—The following papers, mostly descriptive of individual wet-process plants, contain sufficiently detailed data on methods and machinery to be worth referring to as sources of further information. For convenience of reference, the plants have been separately named, though at the cost of some space.

Grimsley, G. P. A new Portland-cement mill in the gas fields of Kansas [Iola]. Engineering and Mining Journal, Feb. 16, 1901.

Lathbury, B. B. The Michigan Alkali Company's plant for manufacturing Portland cement from caustic-soda waste. Engineering News, June 7, 1900.

Lathbury, B. B., and Spackman, H. S. The Michigan Alkali Co.'s plant, Wyandotte, Mich. The Rotary Kiln, pp. 110–119. 1902.
Lathbury, B. B., and Spackman, H. S. Detroit Portland Cement Co., Fenton, Mich. The Rotary Kiln, pp. 86–95. 1902.
Lathbury, B. B., and Spackman, H. S. Wabash Portland Cement Co., Stroh, Ind. The Rotary Kiln, pp. 128–133. 1902.
Lathbury, B. B., and Spackman, H. S. Alma Portland Cement Co., Welleston, Ohio. The Rotary Kiln, pp. 44–51. 1902.
Lathbury, B. B., and Spackman, H. S. Castalia Portland Cement Co., Castalia, Ohio. The Rotary Kiln, pp. 78–81. 1902.
Lathbury, B. B., and Spackman, H. S. Beaver Portland Cement Co., Marlbank, Ontario. The Rotary Kiln, pp. 74–77. 1902.
Lathbury, B. B., and Spackman, H. S. Plant of the Aalborg Portland Cement Fabrik, Aalborg, Denmark. The Rotary Kiln, pp. 42–43. 1902.
Lewis, F. H. The plant of the Bronson Portland Cement Co., Bronson, Mich. Engineering Record, April 30, 1898. Cement Industry, pp. 33–44. 1900.
Lewis, F. H. The plant of the Michigan Portland Cement Co., Coldwater, Mich. Engineering Record, Feb. 25, 1899. Cement Industry, pp. 78–84. 1900.
Lewis, F. H. The Empire Portland-cement plant, Warners, N. Y. Engineering Record, July 16, 1898. Cement Industry, pp. 45–51. 1900.
Lewis, F. H. The Buckeye Portland-cement plant, near Bellefontaine, Ohio. Engineering Record, Oct. 15, 1898. Cement Industry, pp. 52–59. 1900.
Lewis, F. H. Western Portland Cement Co.'s plant, Yankton, S. D. Engineering Record, Nov. 19, 1898. Cement Industry, pp. 60–68. 1900.
Russell, I. C. The Portland-cement industry in Michigan. 19th Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 629–685. 1902.
Simmons, W. H. [Plant at Bronson, Michigan.] Proc. Inst. Civ. Engrs., vol. 145, pp. 120–121. 1901.
Stanger, W. H., and Blount, B. [Plant at Bronson, Mich.] Proc. Inst. Civ. Engrs., vol. 145, pp. 68–69. 1901.
Anon. Plant and buildings of the Hecla Portland Cement and Coal Co., Mich. Engineering News, vol. 51, pp. 243–245. 1904.

General Crushing Practice.

The crushing and grinding practice in cement-making is so important a part of the manufacture, and so closely connected with the financial success or failure of the plant, that it requires special consideration, both as to general methods and in regard to the special types of machinery employed. In the present section certain features will be discussed which are common to both the wet and dry methods of preparation, while the following chapter will be devoted to a description of the various standard types of crushing and grinding machinery.

Necessity for fine grinding.—The necessity for very fine grinding of the raw mixture, if a sound and volume-constant cement is to be obtained, was early stated by Newberry,* and the value of such fine grinding has been recently expressed in the quantitative form by the experiments of Professor Campbell.†

To secure a sound and volume-constant cement it is necessary that the raw mixture be very finely ground. Other things being equal, the finer the grinding of the raw mixture the better will be the resulting cement. The degree of fineness necessary to secure a given grade of cement will depend upon:

(*a*) The percentage of lime in the mixture. The higher the percentage of lime in the mixture, the finer the raw mixture must be ground, because the chances of getting an unsound or expensive cement will increase as the percentage of lime rises, and this tendency will have to be counteracted by greater fineness of grinding.

(*b*) The carefulness with which the materials have been mixed. The more careful and thorough the mixture, the less care need be bestowed upon the grinding, and vice versa.

(*c*) The character of the raw materials. This point, which has been emphasized by Newberry,* is of great importance. When a very pure limestone or marl is mixed with a clay or shale, the grinding must be much finer than in the plants (such as those in the Lehigh district of Pennsylvania) where a highly argillaceous limestone ("cement rock") is mixed with a comparatively small quantity of purer limestone. In the latter case the coarser particles of the argillaceous limestone will be so near in chemical composition to the proper mixture as to do little harm to the resulting cement, even if both the grinding and the mixing should be incompletely accomplished, while in the former case, where a pure limestone or marl is mixed with clay or shale, both of the constituents are very different in composition from the proper mixture, and coarse particles will therefore be highly injurious to the cement.

(*d*) The duration of the burning. In the old-fashioned dome kilns, where the mixture was exposed to the action of heat for a week or more, the duration of the burning compensated in some degree for the lack of thoroughness in grinding or mixing. In modern rotary kilns, however, in which the mixture is burned for only an hour or so, this aid cannot be counted on, and both grinding and mixing must therefore be done more carefully.

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* 20th Ann. Rept. U. S Geol. Survey, pt. 6, p. 545.

† Journ. Am. Chem. Soc., vol. 25, p. 40 et seq.

Actual fineness attained.—After its final reduction, and when ready for burning, the mixture will usually run from 90 to 95 per cent through a 100-mesh sieve. In the plants of the Lehigh district the mixture is rarely crushed as fine as when limestone and clay are used. Newberry * has pointed out in explanation for this that an argillaceous limestone (cement rock) mixed with a comparatively small quantity of purer limestone, as in the Lehigh plants, requires less thorough mixing and less fine grinding than when a mixture of limestone and clay (or marl and clay) is used, for even the coarser particles of the argillaceous limestone will vary so little in chemical composition from the proper mixture as to affect the quality of the resulting cement but little should either mixing or grinding be incompletely accomplished.

A very good example of typical Lehigh Valley grinding of raw material is afforded by a specimen examined † by Prof. E. D. Campbell. This specimen of raw mix ready for burning was furnished by one of the best of the eastern Pennsylvania cement-plants. A mechanical analysis of it showed the following results.

Mesh of sieve	50	100	200
Per cent passing	96.9	85.6	72.4
Per cent residue	3.1	14.4	27.6

The material, therefore, is so coarsely ground that only a trifle over 85 per cent passes a 100-mesh sieve.

Bleininger has recently published the results of a series of tests for fineness, made on the raw mixtures used by various plants. The results are given in Table 175.

Gradual vs. one-stage reduction.—This question is now of little more than theoretical interest, as almost all cement-plants seem to have given the same decision in regard to it Until within the past few years, examination of a number of cement-plants would have developed the fact that two radically different systems of reduction were in use. Reference is made to the "gradual" and "one-stage" methods.

In those earlier days many plants, after preliminary treatment in a coarse crusher, completed the entire process of further reduction in a Griffin mill or ball mill, for it must be recollected that the latter mill was introduced earlier than its companion, the tube mill, and was at first expected to do the work now done by both.

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* 20th Ann. Rep. U. S. Geol. Survey, pt. 6, p. 545.

† Jour. Amer. Chem. Soc., vol. 25, p. 39.

TABLE 175.

FINENESS OF RAW MIX AT VARIOUS PLANTS. (BLEININGER.)

Cement No.	Raw Materials.	Method.	Reduced by	Residue on 80-mesh Sieve.	Residue on 120-mesh Sieve.	Residue on 200-mesh Sieve.	Diam. between 0.0088 and 0.0004 inch.	Diam. between 0.0016 and 0.0002 inch.	Diam. between 0.0011 and 0.00014 inch.	Finer than Last Size.
			Mills.							
1	Limestone and shale	Dry	Emery	2.00	9.89	4.85	16.93	8.96	8.70	48.68
2	Cement rock and limestone........	Dry	Griffin	16.38	11.57	4.75	16.21	13.29	7.61	30.17
3	Cement rock and limestone........	Dry	Tube	3.03	7.42	3.68	23.77	17.52	10.26	34.33
4	Limestone and clay	Wet	"	7.40	9.56	2.48	17.72	8.96	8.83	45.05
5	Marl and clay......	Wet	"	3.04	5.50	5.21	20.31	12.63	9.61	44.72
6	" " "	Wet	"	30.46	4.28	2.17	6.73	10.61	9.31	47.06
7	" " "	Wet	"	2.48	5.23	2.47	16.14	14.22	12.01	47.46
8	" " "	Wet	"	26.74	6.99	2.13	10.52	9.77	7.67	36.18

At present, however, the "one-stage" type of fine-reduction practice has fallen into disuse. It has been gradually modified out of existence, so that cement-mills now are all using a gradual reduction system.

The change from "one-stage" to "gradual" has been effected in two opposite ways, according to whether Griffin or ball mills were in use at the original plant. In plants using the Griffin (or Huntingdon) mill, it has finally become the general practice to place either a fine gyratory crusher or a set of fairly fine rolls between the coarse crusher and the Griffin mill, thus insuring that the material fed to the Griffin mill shall not be over ½ or even ¼ inch in size. In plants using ball mills, the change has taken place at the latter end of the series by putting in a tube mill after the ball mill. The ball mill, instead of taking a coarse product from the crusher and reducing this product to its ultimate fineness, has been made an intermediate reducer, the final reduction taking place in the tube mill.

Present-day systems.—Present-day practice in the reduction of dry raw materials may therefore be summarized as in the following two schedules. The two schemes differ from each other mainly in the mills used.

TYPE A. GRIFFIN (OR HUNTINGDON) MILL TYPE.

1. Gyratory crusher........ to about 2½ inches
2. Crusher or rolls......... " " ¼ to ½ inch
3. Griffin or Huntingdon mill " " 85 to 95% through 100-mesh

TYPE B. BALL (OR WILLIAMS) MILL TYPE.

1. Gyratory crusher........ to about 2½ inches
2. Kominuter, ball mill or Williams mill......... " " 20- to 30-mesh
3. Tube mill.............. " " 85 to 95% through 100-mesh

The omission of separators in cement-plants.—Practically every writer who has discussed the crushing practice at American Portland-cement plants has noted and deplored the absence of separators. In spite of this general unity of opinion in the subject, only a few plants, to the writer's knowledge, are now equipped with any separators, and none have as many as might be used. In view of the fact that American Portland-cement practice, so far as crushing methods are concerned, is to-day far ahead of crushing practice in ore-treatment works, this apparent disregard of one great principle of general crushing practice seems to require some explanation. It will not do merely to assume that separators are omitted because the advantages to be gained from their use are not understood by designers and managers of cement-plants, for that amounts to charging a peculiarly expert clan of mechanical experts with gross ignorance. In the opinion of the writer, the general omission of separators is entirely justified by certain conditions peculiar to the process of Portland-cement manufacture, and the general use of separators would be a serious error in this business. As this opinion may not be generally accepted, and as the grounds on which it is based have never been discussed in print, the advantages and disadvantages of separators may be worth discussing in some detail. This is particularly necessary because the writer realizes, and freely admits, that the views which he holds may be proven to be based on incorrect premises. In that case a relatively brief series of experiments, which could be carried on in any cement-mill, would be of great service to all interested in the technology of the cement industry.

Advantages of separators.—In crushing any material, if the only things to be arrived at are low cost of crushing per ton of product and high tonnage of product per hour, one fact may be regarded as firmly established; that is, that it is an error to feed to any machine (of the series of reducers employed) material fine enough to go to some machine further along in the reduction process. Beginning with the first or coarsest crusher of the series, while most of its product will only be fine, a certain part of its product will be sufficiently fine to be passed on to the third or even fourth reducer. If this be done the product per hour of the series will be greatly increased, each machine will be working on material of fairly uniform size, and the cost of crushing per ton will be greatly reduced.

Applying this to the Portland-cement industry it is probably safe to say that in a series of reducers (consisting for example of a coarse crusher, a fine crusher, a Williams or ball mills and tube mills) the product per hour of the series could be increased at least 50 per cent by simply placing separators between each of the steps of the series. The cost of crushing per ton of product would incidentally be decreased, but not in quite the same ratio.

Disadvantages of separators.—In view of the enormous gain in output that would be secured by the use of separation, as noted in the preceding paragraph, it is evident that the *disadvantages* attending their use must also be very great, for otherwise every cement-mill would now be fully equipped with them. The principal disadvantages attending the use of separators in a Portland-cement plant are two:

1. Separators destroy the uniformity of the product.
2. Separators prevent the attainment of very great fineness.

These two objections will be discussed in the order named. It is probable that the second is in actual practice the more important.

Uniformity of product destroyed by separators.—Throughout the entire course of cement manufacturing processes, from the moment the raw materials enter the will until the finished cement is packed the object of the manufacturer is to attain a product as nearly homogeneous as possible. The quality of the cement depends in large part on the extent to which his attempts to secure absolute uniformity have been successful. In the opinion of the present writer, one great objection to the introduction of separators into cement practice is that their use will tend to destroy this uniformity.

The action of separators is based commonly on one of two principles. They take advantage either (*a*) of differences in the weight of particles or (*b*) in differences of size of particles. In the first case, the separator, other things being equal, will take out both the finer particles and the particles of lowest specific gravity. In dealing with raw mixtures they will tend to separate the clay particles from the limestone particles. Separators depending for their action on the differences in size between the particles will take out the finer, which, other things being equal, will, of course, be particles of the constituent which is most readily pulverized. Similar effects will be observed if separators be used in the progress of clinker-grinding, for the lighter-burned, more readily ground portions will be separated from the rest and the uniformity of the product will be destroyed.

Great fineness prevented by separators.—If in a plant not using separators the finest grinders be adjusted to give a product of which 95 per cent passes a 100-mesh sieve, a very large proportion of that product (say 70 to 75 per cent) will pass a 200-mesh sieve. If separators were installed throughout the plant, and the same adjustment of the fine grinders maintained, a product passing the same 95 per cent through a 100-mesh sieve would probably pass not over 60 per cent through 200-mesh. As it is the percentage of very finely ground particles which gives the chief value to the cement, the use of separators on the clinker-grinding side of a cement-plant would seem to be inadvisable. In pulverizing raw materials the same objection can be made, though it is not so important as in grinding the finished product.

The following papers contain data on the subject of separators:

Eckel, E. C. Some of the reasons why separators are not used in Portland-cement works. Engineering News, vol. 51, p. 344. April 7, 1904.

Fraser, G. H. Recent results obtained with the Kent mill as a fine grinder. Cement, vol. 6, pp. 74–79. May, 1905.

Humphrey, R. L. The plant of the Buckhorn Portland Cement Co. Engineering News, vol. 50, pp. 408–414. Nov. 5, 1903.

Michaëlis, W., jr. Air separation of cement. Cement and Engineering News, vol. 15, p. 2. Oct., 1903.

CHAPTER XXXV.

STANDARD TYPES OF CRUSHING AND PULVERIZING MACHINERY

It has seemed advisable to devote a chapter to the description of various standard types of crushing and pulverizing machinery. In selecting the particular machines to be described in this chapter, the writer has attempted to include those, and only those, which are known to him as being in satisfactory operation at one or more American cement-plants. It is possible that in endeavoring to exclude worthless types some meritorious machines may have been unintentionally neglected; but it is safe to say that over 95 per cent of the cement made in this country is crushed and pulverized by machines described in the following pages.

In describing the various types of crushers and pulverizers, the drawings of the mills and the data relative to their construction and mechanical operation have been taken mostly from trade catalogues or from descriptions prepared by the manufacturers. The data on output, fineness and power required were, however, in almost all cases obtained from managers of cement-mills, and are believed to be entirely reliable.

Classification of Grinding Machinery.

So many types and varieties of crushing and pulverizing machinery are now on the market that it is difficult, from a single description, to form much of an idea of the relation of any given one of these machines to any of the others. To aid in this, the machines described in the following pages have been grouped under eight classes, according to their general methods of action. This grouping is as follows:

Class 1. JAW CRUSHERS; material crushed between two jaws which approach and recede.................................. BLAKE CRUSHER.

Class 2. CONE GRINDERS; material crushed by the revolution of a toothed cone or spindle within a toothed cup...... GATES CRUSHER, CRACKERS.

Class 3. ROLLS; material crushed between two or more plain, fluted, or toothed cylinders revolving in opposite directions.................. ROLLS.

Class 4. MILLSTONES; material crushed between two flat or grooved discs, one of which revolves.

MILLSTONES, BUHRS, STURTEVANT EMERY MILLS, CUMMINGS MILL.

Class 5. EDGE-RUNNERS; material crushed in a pan, under a cylinder turning on a horizontal axis and gyrating about a vertical axis.

EDGE-RUNNERS, DRY-PAN.

Class 6. CENTRIFUGAL GRINDERS; material crushed between rollers and an annular die, against which the rollers are pressed by centrifugal force.

HUNTINGDON MILL, GRIFFIN MILL, NAROD MILL, CLARK PULVERIZER.

Class 7. BALL GRINDERS; material crushed by balls or pebbles rolling freely in a revolving horizontal cylinder.

KOMINUTER, BALL MILL, TUBE MILL.

Class 8. IMPACT PULVERIZERS; material crushed by a blow in space delivered by revolving hammers, bars, cups, or cages.

WILLIAMS MILL, RAYMOND PULVERIZER, STURTEVANT DISINTEGRATOR, STEDMAN DISINTEGRATOR, CYCLONE PULVERIZER.

Class 1. Jaw Crushers.

In this familiar type of coarse crushing machines, of which the Blake crusher is both the oldest and best-known representative, the material is fed between two powerful jaws, and crushed by their near approach to each other. The principle upon which these machines work is well adapted for *breaking* stone, but is not serviceable for finer reduction. The Blake crusher in its various forms, and the Dodge and other devices of the movable-jaw type, are therefore machines suitable for first reduction only.

For detailed descriptions of the Blake crusher, and of the modifications in which the same principle has appeared, reference should be made to the valuable paper cited below.*

In mining and metallurgical practices jaw crushers are commonly used, but in the cement industry they have almost entirely given place to the gyratory crushers described in the next section.

Class 2. Cone Grinders; Gyratory Crushers.

Under this heading are grouped the crushing machines in which the material is crushed between a toothed or grooved cone or spindle and the grooved cup within which it revolves. The Gates crusher, the Mosser crusher, and the McEntee and other "crackers" are here

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* Blake, W. P. The Blake stone and ore-breaker: its invention, forms, and modifications, and its importance in engineering industries. Trans. Amer. Inst. Mining Engineers, 1903, pp. 988–1031.

included. The "crackers" have been described quite fully on page 239, in dealing with the crushing practice in natural-cement plants, and the Mosser crusher is of essentially the same design as these crackers, though built for heavier work.

The Gates crusher, shown in view in Fig. 87, and in section in Fig. 88, is probably the most extensively used machine of its type. In regard to its power requirements, capacity, etc., its manufacturers state:

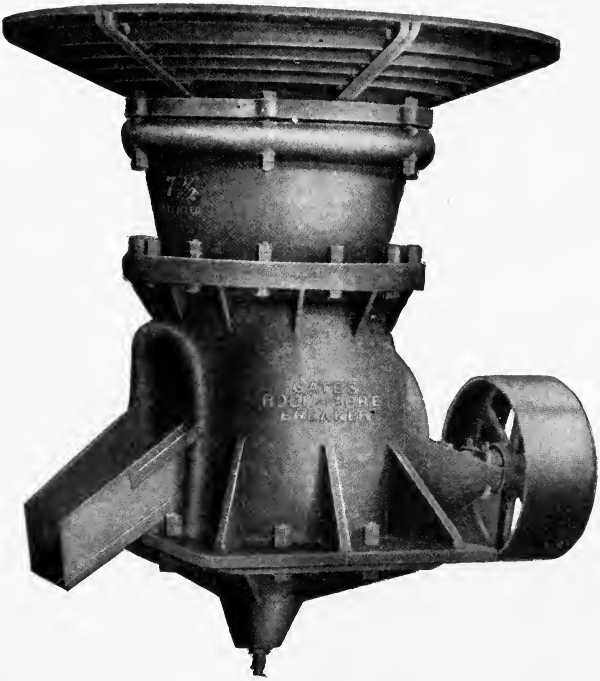

Fig. 87.—External view of Gates crusher.

"In estimating power to drive our breakers we have provided for running an elevator and screen also. But it must be borne in mind that no close estimate can be made to cover all sorts of rock and ore; and further, it should be observed that it requires much more power per ton to break rock to ½ inch than is required to break it to an inch. The estimates given in Table 176 are intended to cover the ordinary macadam breaking. For fine breaking add liberally to the power. Long experience has demonstrated the reliability of the following general rule, applicable to breaking the hardest rock to 2½-inch ring, viz.: The Gates breaker will not require over one horse-power per ton of rock broken per hour."

The estimate (see Table 177) of the cost of crushing with a Gates crusher is based by Professor Richards on the results of a number of mill tests at ore-treatment plants. As the ore handled at these mills was, in general, harder than the raw materials used in Portland-cement manufacture, allowance should be made for this feature.

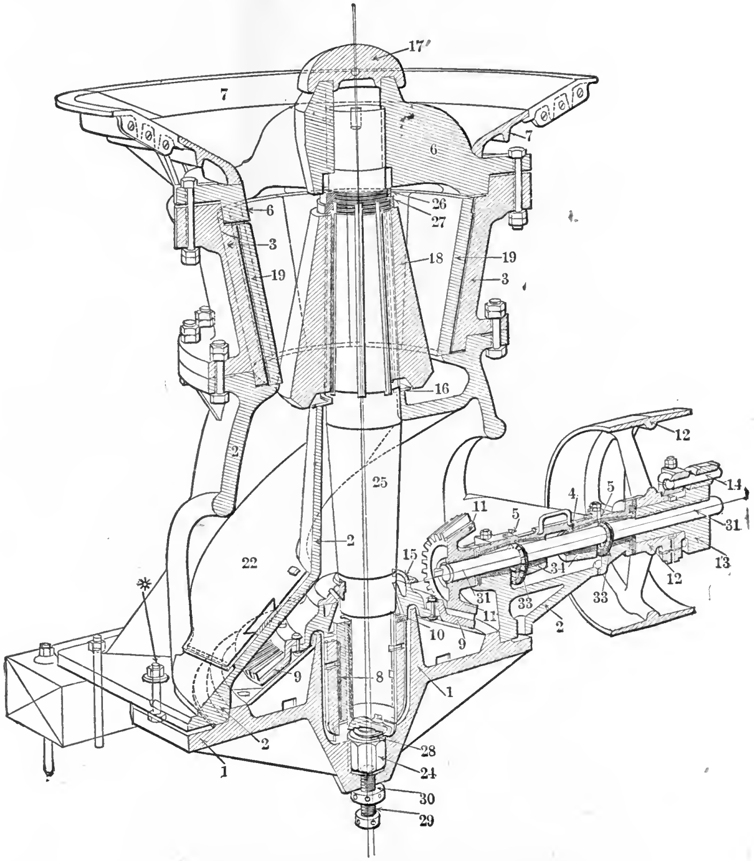

FIG. 88.—Sectional view of Gates crusher.

The names of the several parts designated by numbers in the above illustration may be found in the following table:

1. Bottom plate
2. Bottom shell
3. Top shell
4. Bearing-cap
5. Oil-cellar cap
6. Spider
7. Hopper
8. Eccentric
9. Bevel-wheel
10. Wearing-ring
11. Bevel-pinion
12. Band-wheel
13. Break-pin hub
14. Break-pin
15. Oil-bonnet
16. Dust-ring
17. Dust-cap
18. Head
19. Concaves
22. Chilled wearing-plates
24. Octagon step
25. Main shaft
26. Upper ring nut
27. Lower ring nut
28. Steel step
29. Lighter screw
30. Lighter screw, jam nut
31. Counter-shaft
33. Oiling-chain

TABLE 176.

SIZES, POWER, ETC., OF GATES CRUSHERS.

Size.	Dimensions of Each Receiving Opening Inches.	Dimensions of Receiving Openings Combined Inches.	Weight of Breaker, Lbs.	Capacity per Hour, in Tons of 2000 Lbs., Passing 2½-inch Ring, According to Character of Rock or Ore.	Smallest Size Product can be Made at One Break, Inch.	Dimensions of Driving-pulley, Inches.		Revolutions of Driving-pulley.	Size Engine Recommended to Drive Breaker, Elevator, and Screen. Indicated Horse-power.
						Diam.	Face.		
F	2×6	2×12	650	....	⅜	8	2⅝	700	1 to 1½
H	7×18	7×54	11,800	....	½	24	4	600	10 " 15
0D	4×15	4×30	3,550	2 to 4	⅝	16	6	500	4 " 5
1D	5×18	5×36	5,500	4 " 8	¾	20	7	475	8 " 10
2D	6×21	6×42	8,000	6 " 12	1	24	8	450	12 " 15
3D	7×22	7×45	14,000	10 " 20	1¼	28	10	425	20 " 25
4D	8×27	8×54	21,000	15 " 30	1½	32	12	400	25 " 30
5D	10×30	10×60	30,000	25 " 40	1¾	36	14	375	30 " 40
6D	11×36	11×72	42,000	30 " 60	2	40	16	350	40 " 60
7½D	14×45	14×90	63,000	75 " 125	2½	44	18	350	75 " 125
7½K	14×45	14×90	67,000	75 " 125	2½	44	18	350	75 " 125
8D	18×63	18×126	94,000	125 " 200	3	48	20	350	100 " 150
8L	18×63	18×126	91,500	125 " 200	3	48	20	350	100 " 150
9K	21×48	21×144	155,000	300 " 500	4	56	20	300	100 " 150

TABLE 177.

ESTIMATED COST OF CRUSHING BY GATES CRUSHER.*

Number of crusher	0	2	4	6	8
Size of mouth in inches	4×30	6×42	8×54	11×72	18×126
Tons crushed in twenty-four hours	72	216	540	1080	3000
Horse-power used	3	9	22	45	125
List price of crusher	$375	$760	$1800	$3300	$7000
	Cost in Cents per Ton Crushed.				
Cost of oil	0.021	0.021	0.021	0.021	0.021
" interest and depreciation	0.169	0.114	0.108	0.099	0.076
" of power	0.541	0.541	0.541	0.541	0.541
" " labor	5.556	1.852	0.741	0.370	0.133
" " wear	0.971	0.971	0.971	0.971	0.971
" " repairs	0.308	0.308	0.308	0.308	0.308
Total	7.566	3.807	2.678	2.310	2.050

Class 3. Rolls.

In the group of crushing machines here considered the material is crushed between two or more cylinders which revolve in opposite directions. These cylinders may be plain-surfaced, longitudinally fluted, or toothed, according to the character of work they are expected to perform. As the fineness of the product is regulated chiefly by the

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* Richards, R. H. Ore Dressing, vol. 1, p. 50. 1903.

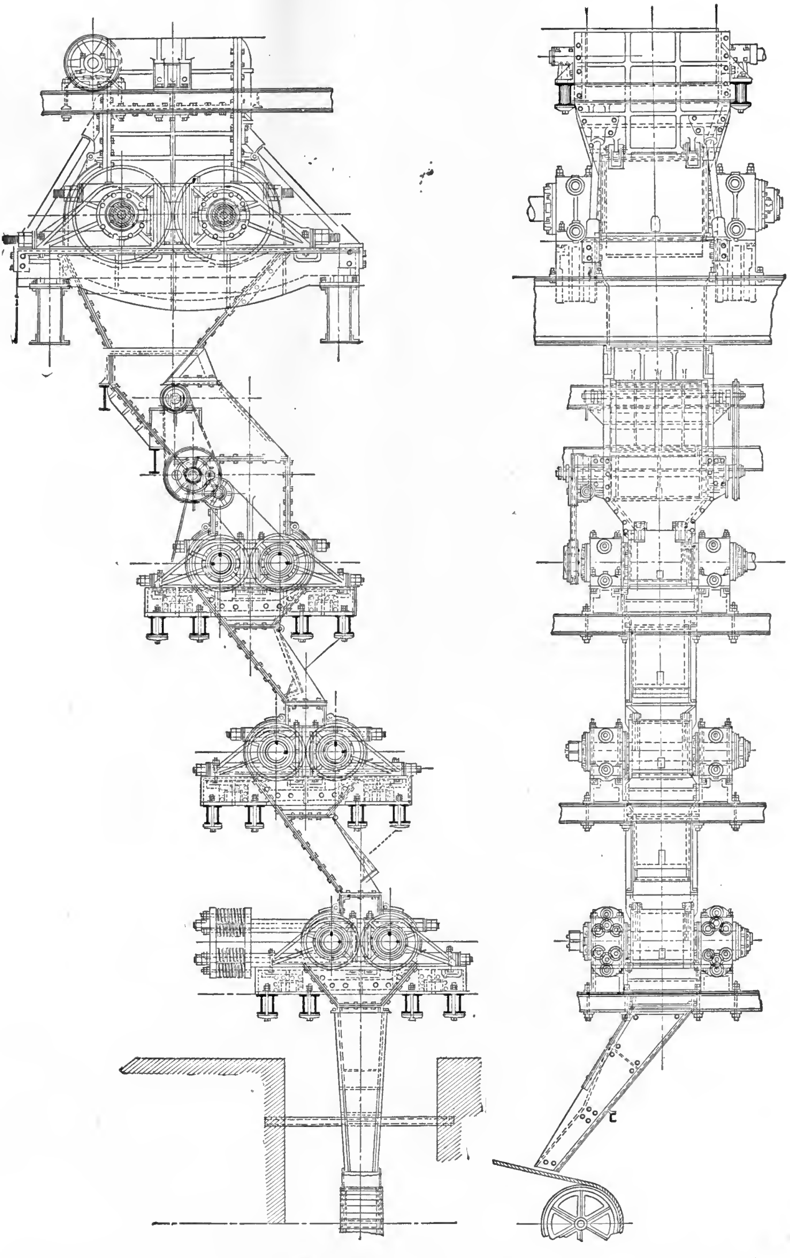


FIG. 89.—Elevation of rock-crushing system, Edison plant. (The Iron Age.)

closeness with which the cylinders are set, it is obvious that we have here a type of machine very different from the jaw crushers and cone grinders previously discussed, for rolls can be used for either coarse or fine grinding.

By far the most extensive use of rolls in the cement industry is made at the Edison plant at Stewartsville, N. J., where all the crushing and grinding on both the raw and clinker sides of the mill is accomplished in rolls. At other plants rolls are used, if at all, only for crushing clinker, direct from the kilns, to a size that can be economically handled by Griffin, Huntingdon or ball-mills.

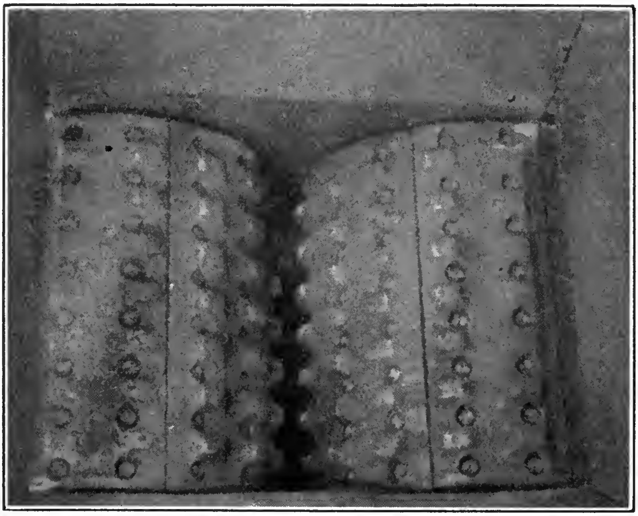
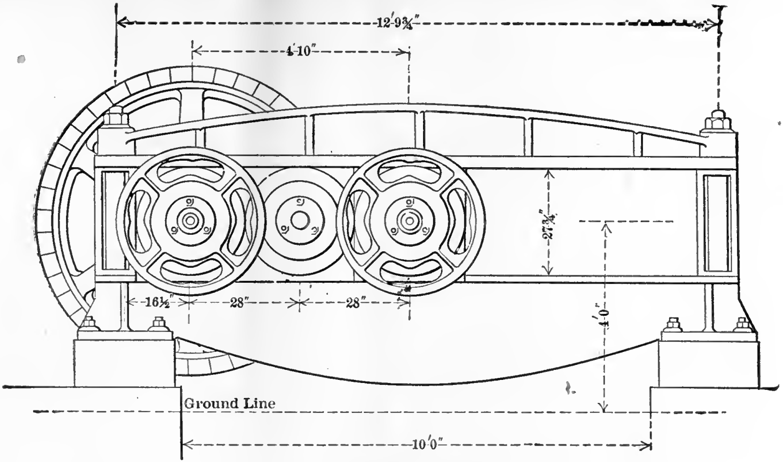


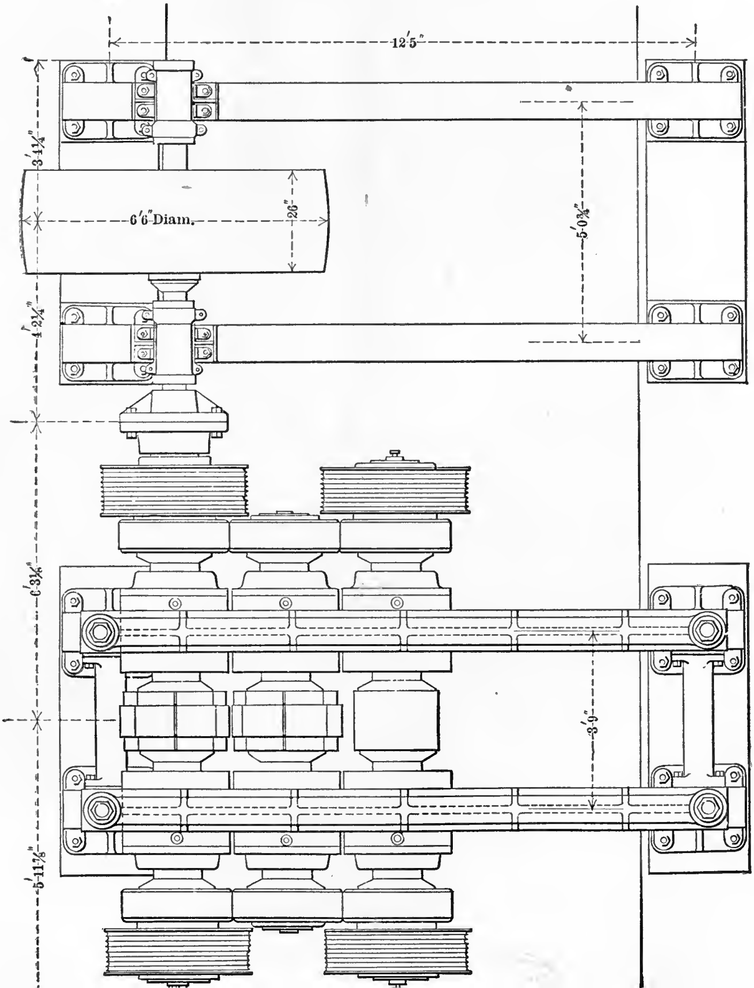
Fig. 90.—View looking down between 5-foot rolls, Edison plant. (Engineering News.)

At the plant of the Edison Portland Cement Company the raw materials are crushed and pulverized in a series of rolls of special design. The elevation of this series is shown in Fig. 89, while Fig. 90 is a view looking downward on one of the coarser sets of rolls. In Fig. 91 the plan and elevation of the fine-grinding rolls of the Edison plant are presented.

With the exception of the Edison plant, however, rolls are rarely or never used for fine grinding in Portland-cement practice on either the raw or clinker sides of the mill. They are commonly used in coal crushing, particularly when lump or run-of-mine coal is bought (see pp. 514, 515); and in many plants they are used as a first reducer on



SIDE ELEVATION



clinker. For this last purpose they are specially well adapted, because they can handle hot clinker with less injury than any other form of grinding machinery.

Class 4. Millstones.

This class of crushing machinery includes those types in which the material is ground between two flat or grooved discs, one of which revolves. These discs are usually set horizontally, though they may also be arranged vertically. The class includes the millstones and buhrstones proper, and several patented devices such as the Sturtevant rock-emery mill and the Cummings mill. As these machines are extensively used in grinding natural-cement clinker, they have been already described under that head (pp. 239–243). In Portland-cement practice they are now rarely used, though in the old-style wet-process plants millstones were almost invariably adopted.

At one small Portland-cement plant seven runs of 48-inch upper-runner French buhrstones were employed in taking ¼-inch clinker from the rolls and reducing it to about 20-mesh. Each run of stones required 8 H.P. and handled about two barrels of clinker per hour. A sieve test showed the following results:

Mesh of sieve	20	30	50	100
Per cent passed	98	96	92	65
Per cent residue	2	4	8	35

The seven mills required about one man's time for dressing. The particular economy of the installation lay in the fact that the mills cost only about $10 per run, having been purchased from old flour-mill plants. New mills of similar type would cost about $250 each.

Class 5. Edge-runners.

The class of edge-runner mills includes those types in which the material is crushed in a pan under a cylinder, the cylinder having two motions—turning on itself on a horizontal axis and also revolving as a whole about a fixed vertical axis. The familiar "dry-pans" and "wet-pans" of brick-plants are here included, a modern dry-pan of improved type being shown in Fig. 92. In the Portland-cement industry, particularly in wet-process plants, dry-pans are much used in grinding the clay or shale. Elsewhere they are of little service.

Clay is ground in a dry-pan, at one marl-plant, at the rate of 6 tons per hour, the dry-pan requiring about 30 H.P. for operation. This power figure seems unusually high, for at other plants the dry-pan doing similar work is usually estimated as taking about 15 H.P.

A dry-pan used on fairly hard shale at another wet-process cement-plant takes fragments up to 4″×8″ in size and reduces them to about 8-mesh. It requires about 20 H.P. and gives a product of about 6 tons per hour.

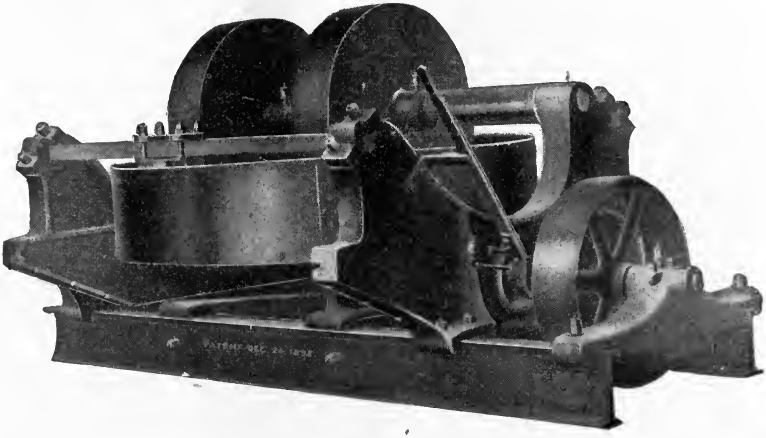


Fig. 92.—Dry-pan. (Allis-Chalmers Co.)

Class 6. Centrifugal Grinders.

In the more typical examples of this class of mills the material is crushed between a horizontal die ring and one or more vertically hung rollers which are held against the ring by centrifugal force. Such typical examples among cement-grinding machinery are the Huntingdon and Griffin mills. A somewhat different arrangement exists in the Kent mill, which is included here for convenience. In this mill the ring is set vertically and the three rolls horizontally. Only one of the rolls is positively driven, the other two rolls and the ring taking motion from the driven roll.

The mills of this class have been used as one-stage reducers at a number of cement-plants, taking raw material or clinker in $\frac{1}{2}$- to 1-inch sizes and reducing it to 85 to 95 per cent through a 100-mesh sieve, and they have accomplished this task with a fair degree of efficiency. Of late years, however, the tendency has been very markedly in favor of lightening this task by putting in tube mills for the final reduction.

Huntingdon mill.—The Huntingdon mill as used in the manufacture of Portland cement is a slightly modified form of the mill of the same name used in gold-ore treatment. The rights of the Huntingdon mill for the cement industry are controlled by the Atlas Portland Cement Company. The mill has in consequence been used only in the plants of that company, where it seems to have given good satisfaction.

In the Huntingdon mill three heavy rollers are suspended from a circular horizontal head, the attachment being such as to allow free radial swing to the rollers. The rapid revolution of the head causes the rollers to diverge, swinging outward, and being pressed by centrifugal force against a horizontal annular die ring of steel. The material fed in is pulverized between this fixed ring and steel-head rings attached to the bottom end of each roller. The mill, therefore, differs from the Griffin mill, chiefly in the fact that the single roller of the latter mill is revolved positively by power applied directly to its upper end, while in the Huntingdon mill the individual rollers are not positively rotated.

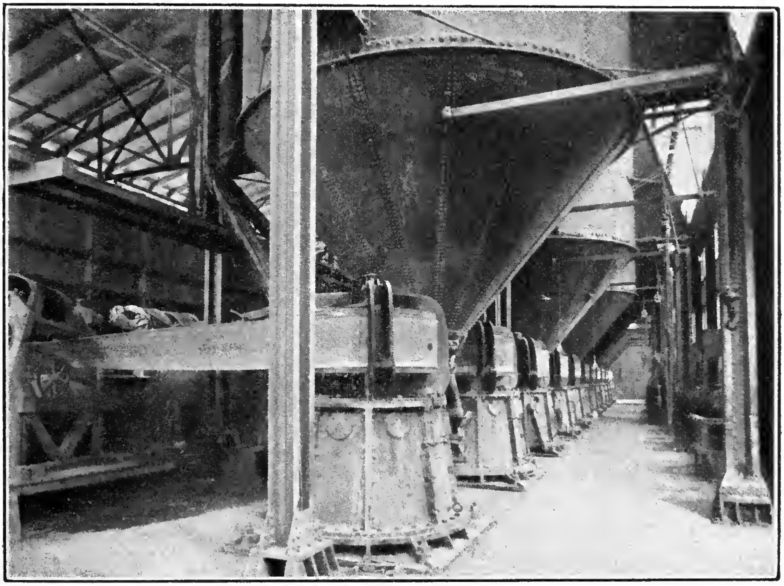


Fig. 93.—Huntingdon mills at Atlas plant. (Atlas Portland Cement Co.)

A Huntingdon mill requires about 40 H.P. If fed with material varying from ½ to 1 inch in size, its output on clinker will be about 8 barrels per hour, ground so as to pass 92 per cent through a 100-mesh sieve. On raw material its output will vary from 15 to 25 barrels per hour, ground to pass 93 per cent through a 100-mesh sieve. For grinding clinker to a fineness of 90 or 92 per cent on 100-mesh, the Huntingdon mill has given good satisfaction, but for the greater fineness now required by many specifications, it is probable that the finishing work can be done more economically with the tube mill. The rate of grinding clinker, quoted above, is equivalent to an expenditure of 5 H.P. hours per barrel of cement, which is about the same as the work done by the Griffin mill under similar conditions.

Griffin mill.—If we disregard the enormous Atlas plants, the Griffin mill is by far the most extensively used of the class of centrifugal grinders. It is shown in section in Fig. 94.

On reference to this figure it will be seen that the power is received by a pulley (17) running horizontally. From this pulley is suspended the shaft (1) by means of a universal joint (9), and to the lower extremity of this shaft is rigidly secured the crushing roll (31), which is thus free to swing in any direction within the case. This case consists of the base, or pan (24), containing the ring, or die (70), against which the roll (31) works, and upon the inner vertical surface of which the pulverizing is done.

In dry pulverizing, this pan, or base (24), has a number of openings through it downward, outside of the ring, or die, which lead into a pit, or receptacle, from which it is delivered by a conveyor.

Upon this base is secured the screen frame (44), which is surrounded with a sheet-iron cover (45) (in the wet mill this cover is not used), and to the top of which is fastened a conical shield (25), open at the apex, through which the shaft works.

The cut shows the pulverizing roll attached to the lower end of the shaft (1), and just above the roll is the fan (7), which is used in the dry mill, but not in the wet. On the under side of the roll are shown shoes, or plows (5), which are used in both, and varied in shape according to the nature of the work to be done.

The pulley (17) revolves upon the tapered and adjustable bearing (20), which is supported by the frame composed of the standards (23). Two of these standards (23*a*) are extended above the pulley to carry the arms (22), in which is secured the hollow journal pin (12).

Within the pulley is the universal joint from which the shaft (1) is suspended. This joint is composed of the ball, or sphere (9), with trunnions attached thereto. These trunnions work in half boxes (11) which slide up and down recesses in the pulley-head casting (16).

The joint in the pulley is enclosed by means of the cover (13), thus keeping the working parts away from all dust and grit.

The lubricating oil is supplied for all parts needing it through the hollow pin (12).

The roll is revolved within the die in the same direction that the shaft is driven, but when coming in contact with the die it travels around the die in the opposite direction from that in which the roll is revolving with the shaft, thus giving the mill two direct actions on the material to be ground. There is a pressure by centrifugal force of 6000 lbs. brought to bear on the material being pulverized between the roll and die, the united actions being very effective in their combination.

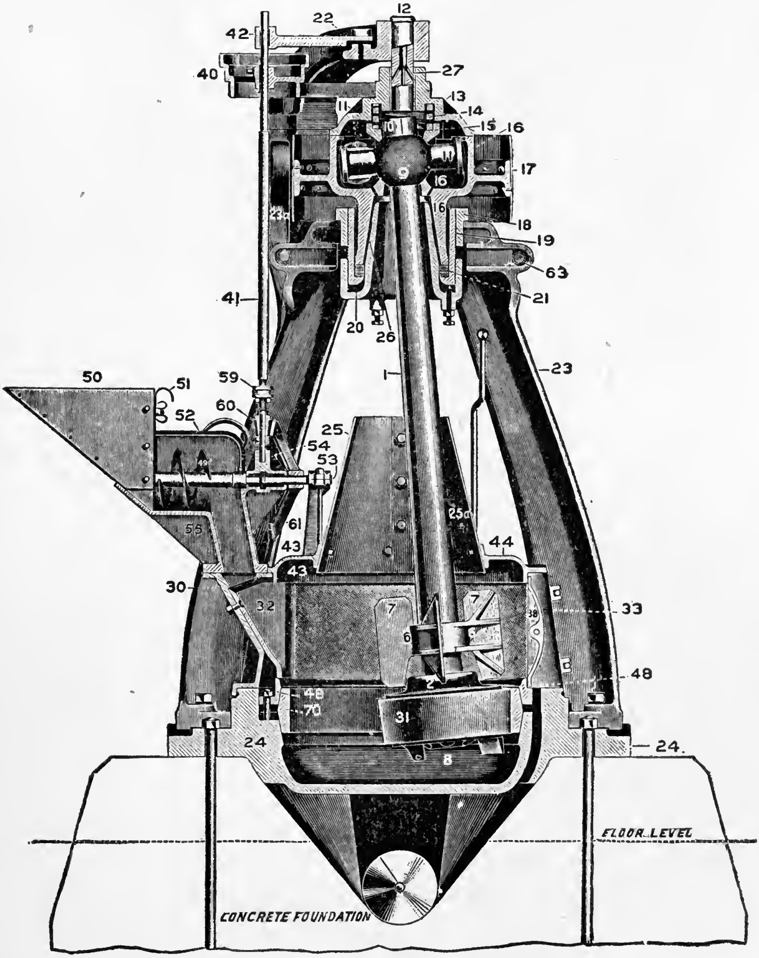


Fig. 94.—Section of Griffin mill.

When a quantity of the material to be reduced has been fed into the mill sufficient to fill the pan as high as the shoes, or plows, on the lower side of the roll, they work in it, stir it up, and throw it against the ring, so that it is acted upon by the roll; and when fairly in operation the whole body of loose material whirls around rapidly within the pan, and, being brought between the roll and die, is crushed, and all that is sufficiently fine passes at once through the screen above the die, the coarser portion falling down to be acted upon again.

The universal joint, by which the shaft is connected with the pulley, allows perfect freedom of movement to the roll, so that it can safely pass over pieces of iron, steel, etc., such as are usually found in all rock to be pulverized, without damage to the mill.

The fan attached to the shaft above the roll draws air in at the top of the cone, forcing it through the screens and out into the discharge, thus effectually keeping all dust within the mill.

In working dry the screen which surrounds the pulverizing chamber is of much coarser mesh than the delivered product; for instance, a 16-mesh screen delivers a product over 90 per cent of which will pass a 60-mesh screen. Two sizes of the Griffin mill are made:

TABLE 178.

SIZES, POWER, ETC., OF GRIFFIN MILL.

	30-inch Mill.	36-inch Mill.
Extreme height of mill above foundation	8 ft. 2½ ins.	8 ft. 7½ ins.
Extreme width of mill	5 " 3 "	6 " 3 "
Height from top of foundation to center of pulley	6 " 4½ "	6 " 6½ "
Weight, complete	10,500 lbs.	14,500 lbs.
Speed of pulley	190 to 200 rev. per min.	135 to 150 rev. per min.
Power required	15 to 25 H.P.	25 to 30 H.P.
Diameter of pulley	30 ins.	40 ins.
Diameter of roll	18 to 20 ins.	22 and 24 ins.
Diameter of ring or die	30 ins.	36 ins.
Depth of contact surface on roll	6 "	6 "
Weight of ring or die	260 lbs.	408 lbs.
Weight of tire	100 "	175 "
Pressure of roll against die	6000 "	8000 "

When running on clinker which has been previously crushed to about ½-inch size the Griffin mill will handle from 5 to 10 barrels per hour, using 25 to 30 H.P. For clinker-grinding the mill is usually equipped with 30- or 32-mesh screens, giving a product of about 95 per cent through a 100-mesh, and 70 to 80 per cent through a 200-mesh.

In grinding raw materials, 24- or 28-mesh screens are used, which, however, give a product practically equal in fineness to the 30- or 32-mesh screens used in clinker-grinding. With these screens the mill will turn out $2\frac{1}{2}$ to 3 tons of raw material (equivalent to 8 to 10 barrels) per hour, taking slightly less power than when running on clinker.

The repair costs of a Griffin mill were stated, at a plant which has always used these mills extensively, to vary with the material crushed in about the following ratio:

Repair costs on clinker : repairs on raw mix : repairs on coal.
11 : $1\frac{1}{2}$: 1

Kent mill.—The Kent mill is a comparatively untried machine, but deserves mention here because of the favorable results reported for it by Professor Newberry, and G. H. Fraser (see p. 468).

The Kent mill is shown in Fig. 95, the casing being broken out, and one fixed check-ring *B* being partly broken away to show the feed chutes *A*, the free revolving ring *C*, the three crushing-rolls *G*, and the bottom discharge outlet *F*.

Referring to the interior view, *A* is the feed-chute, which enters the casing at opposite sides above one of the three rolls *G* and feeds into the angle between this roll and the ring *C*. The three rolls *G* (of which one is driven) are within and support the ring *C*, being drawn yieldingly against its concave inner face at three points by stiff springs acting against the bearing yokes carrying the shafts of the rolls. These yokes slide in lugs on the casing and pull outward according to the adjustment of the springs by their screws. The convex faces of the rolls fitting the concave inner face of the ring hold it in position sideways, so that the ring always tracks on the rolls, but it is also checked against too much side play by fixed check-rings *B* fastened on the inside of the casing at a slight distance from the edges of the free ring, so as to leave a free space *D* between in which the free ring can play and through which the fine material may escape to the discharge chamber *E*, which surrounds the ring *C* and at its lower part meets the discharge outlet *F*. The rings *B* are cut away for a space above the outlet *F*. The fixed rings can be easily replaced if ever worn out.

In operation, the free ring is cushioned by the rolls and held centrally, both axially and laterally, thereby, but can yield to pass a hard substance or to cushion unequal thrusts, and can play sideways between the fixed rings *B* to equalize variations of charge between any roll and the ring. The driven roll drives the ring by contact with its inner face, the other rolls being passive and free to revolve by contact with the ring. The rolls and ring run on each other at like surface speeds. The charge streams in between the ring and one roll, passes the latter, and is carried on the ring past the other rolls, being held against the ring by centrifugal force, due to the speed of revolution, until the particles are reduced to the mesh desired, when they fly off of their own lightness and float inward and fall by gravitation, or pass outward between the free and fixed rings, into the chamber *E* and down there through to the outlet *F*. On entering the mill the charge is set in rapid revolution therein, and is kept revolving until all is reduced. This action is the same whether the charge is great or small. The charge cushions the operation of the mill, the greater the feed the less being the noise and vibration.

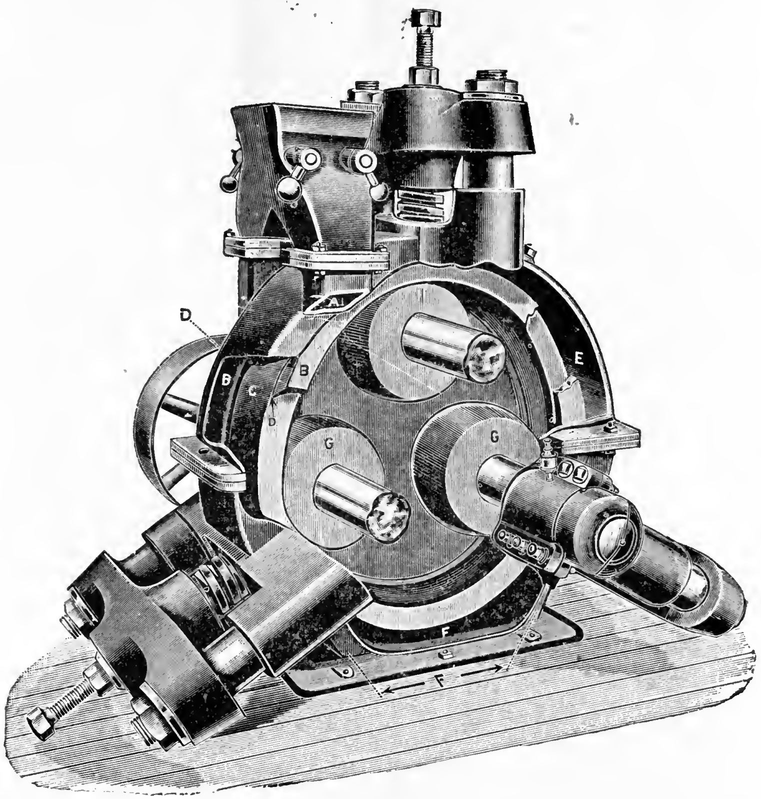


Fig. 95.—Interior of Kent mill.

Gravity doors giving an intermittent feed close the casing against escape of dust. These open every time the weight fed on them is enough to tilt them. The discharge flows out in a large continuous stream of the size for which the mill is adjusted.

Straight belts from any shafting, either directly above or beneath, or at any angle from the mill, are run to the pulleys at each end of the shaft of the driven roll, the speed required being 180 to 200 revolutions for the driving-pulleys. No quartered belts are needed.

Height of mill over all.	6 ft. 6 ins.
Width of mill over all.	6 "
Length of mill over all.	6 " 6 "
Distance from floor to center of driving-pulleys.	2 " 9 "
Weight, complete.	7500 lbs.
Pulley speed.	180 to 200 rev. per min.
Power required (according to fineness and material).	from 15 to 35 H.P.
Diameter of pulleys	30 or 36 ins.
Width of belts.	8 ins.
Diameter of rolls.	14 "
Diameter of ring (inside).	36 "
Width of contact surface on rolls and ring.	7 "
Weight of ring.	800 lbs.
Pressure of each passive roll against ring.	0 to 20,000 lbs.
Pressure of driven roll against ring.	1000 " 21,000 "

LIST PRICES.

Style F "Mining" Mill, complete, f.o.b., N. Y.	$2500
" " " " with separator and 30-foot elevator	3000
" " " " crusher, separator and 30-foot elevator	3500

For the following data on the performance of the Kent mill when handling cement clinker in actual practice the writer is indebted to Prof. S. B. Newberry:

Working as an intermediate reducer on clinker, taking it from the kilns and grinding it to 20-mesh, the Kent mill has given as high as 50 barrels per hour, taking 24 H.P. in doing so. Repairs may aggregate $180 per year per mill. The following table shows the results of several sieve tests of the product from a Kent mill used in this way at a time when it was giving 43½ barrels cement per hour.

Mesh of Sieve.	Per Cent Passing.		
20	99.5	98.5	98.0
100	53.0	49.5	48.0
200	35.0	35.0	33.0

When used as a one-stage pulverizer, taking clinker from the kilns and reducing it to finished cement, a 60-mesh screen being used on the Columbian separator, the Kent mill gave a product of 11.6 barrels cement per hour. A sieve test of this product showed that 97.7 per

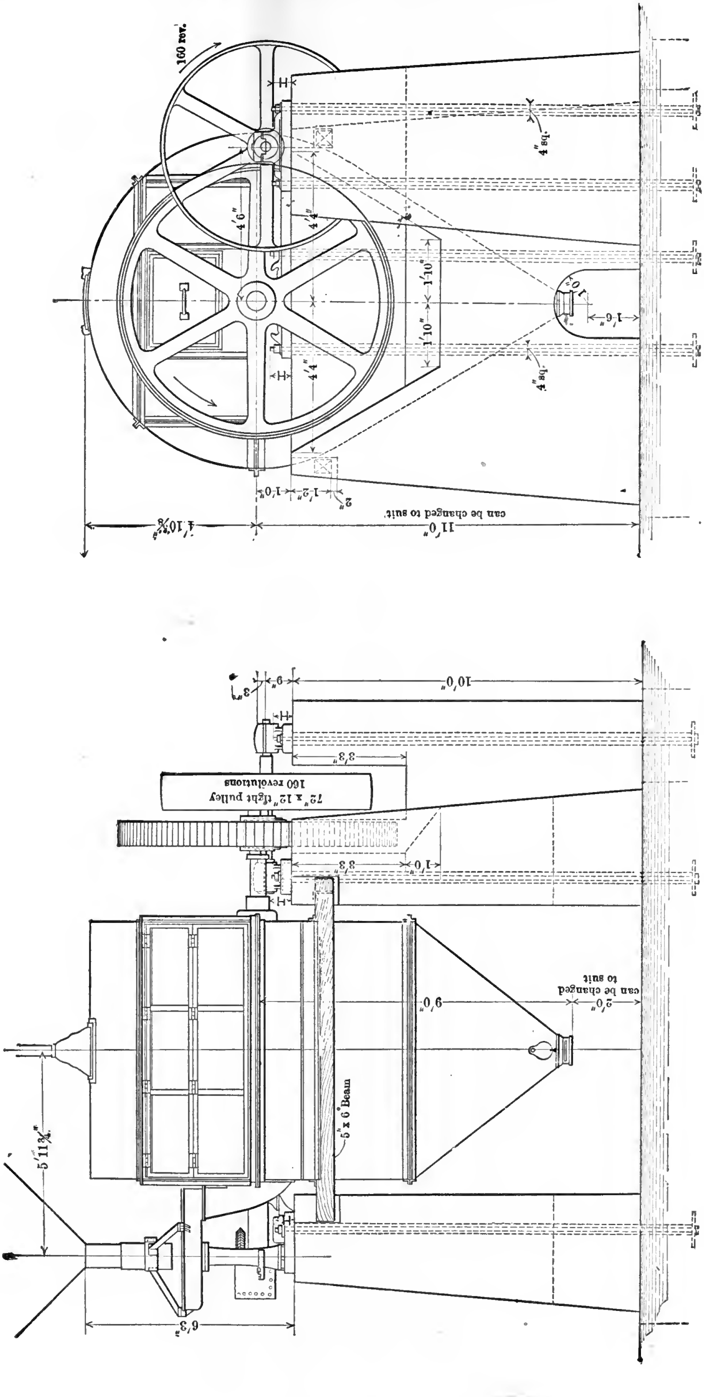
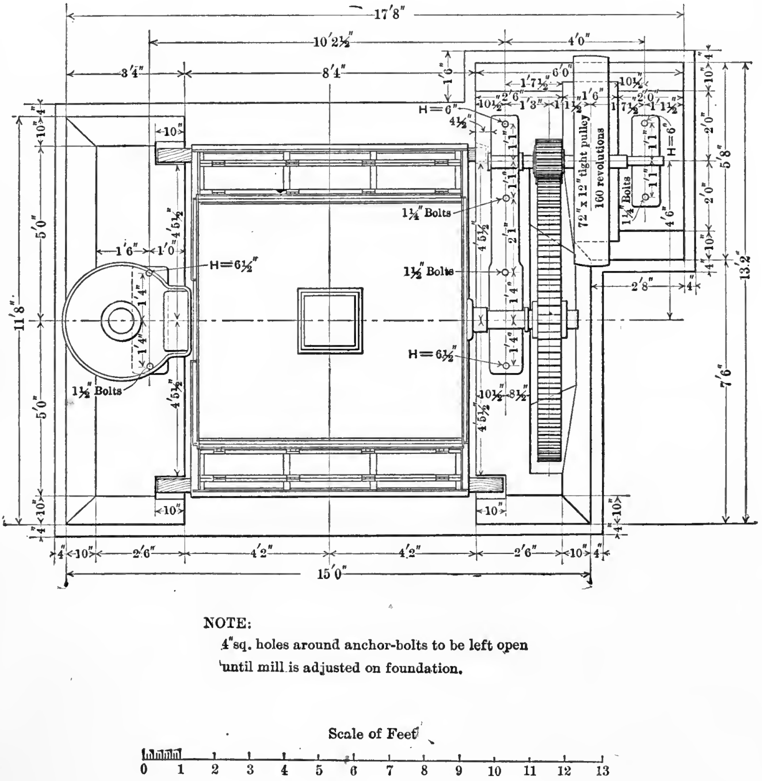


FIG. 96.—Lindhard kominuter, No. 66.

cent of it would pass a 100-mesh sieve and 77.7 per cent passed a 200-mesh.

Class 7. Ball Grinders.

The mills of Class 7 include all those in which the raw material is ground by flint, iron, or steel balls rolling freely in a horizontal or slightly inclined revolving cylinder. Three fairly distinct types are included under this definition, examples of which types are described below under the respective headings of kominuters, ball mills, and tube mills. Of these three types, the kominuter is represented by only one machine, the Lindhard kominuter; but ball and tube mills are made by many manufacturers, the different makes differing slightly in design but often greatly in value.



NOTE:
4″sq. holes around anchor-bolts to be left open
until mill is adjusted on foundation.

FIG. 97.—Foundation plan, Lindhard kominuter, No. 66.

Kominuter.—The Lindhard kominuter, like the ball mill, is a drum-shaped device, about as high as broad, suspended by a shaft passing through the heads and resting on bearings. Outside of this drum is a coarse perforated cylindrical plate, and this in turn is surrounded by a screen frame fitted with wire screening cloth. The material is fed to the kominuter, as in the ball mill, through an opening near the shaft at the head end of the mill. It passes from this to the other end, being ground meanwhile by the balls, because its only place of exit is at the tail end of the kominuter. The discharge material passing thus out of the inner drum, returns in opposite direction over the perforated plates, the coarser particles being returned to the inner drum by curved pipes. Of the material which succeeds in passing the perforated plate the finer particles go also through the final exterior screen and are sent to the tube mills. The coarser particles, rejected by the exterior screen, are returned to the inner drum by two other curved pipes.

This arrangement, while giving a regular and fine product, prevents excessive wear on the wire-cloth screens, since most of the coarser particles do not reach them, being rejected by the perforated plate.

The kominuter was designed to overcome certain disadvantages which have become apparent in machines of the ball-mill type. As stated by the manufacturers of the kominuter, the ball mill had the following defects:

I. Insufficient screen area to prevent materials already ground fine enough from returning to the mill to be acted on again.

II. The gradual closing of the holes in the perforated grinding plates under the peening action of the balls, resulting in a daily decrease in the output from the ball mill.

III. The impracticability of lining the drum with the multiples of a single templet small enough to be handled by one man; that is, the lining is either a set of plates few of which are to the same templet or else a single plate to each face of the polygon, made so large as to require much power to handle.

IV. The lack of means of easy adjustment to allow for the widely varying grindability of materials, as well as for the desired fineness.

The manufacturers present the following comparative statement, designed to show the manner in which these defects have been overcome by the kominuter.

Ball Mill.	Kominuter.
A polygon. Plates, angles, bars, bolts, and rivets machine-fitted and having only the strength of an angular construction, held together with bolts and rivets.	A drum like a section of a steam-boiler.
Perforations in the grinding-plates extend from inlet end to the opposite end, and the material escapes through these throughout the whole length of the grinding surface. The peening gradually closes these perforations, thus constantly reducing the capacity.	The material travels from the inlet end to the opposite end across SOLID grinding-plates and escapes through large openings amply protected from the action of the balls.
Injudicious feeding will pack the material between the perforated exits and the screens, and stop the sieving action. It is frequently necessary to remove the screens to again put the mill into service. Choking damages the screens.	The kominuter can be intentionally overfed until the screens are completely choked. Running the kominuter without feed for 20 min. will clear the screens. The inside screen is usually coarse and strong. It serves to limit the amount of material passing to the outside final screen, and at the same time protects the final screen from excessive wear.
Best obtainable information shows about 40 H.P., operating under normal conditions.	Operating under normal conditions, between 40 and 45 H.P. With maximum charge of balls and materials about 45.
Maximum charge 4400 to 4500 lbs.	Maximum charge 6600 lbs.
Take the ball mill at 100 per cent per ton of balls.	The kominuter has given 125 per cent per ton of balls, as compared with 100 per cent from the ball mill, showing a capacity of about 85 per cent more than that of the ball mill.
The grinding-plates form in part the support for the screens.	The screen device derives its support wholly from the drum itself, and is in no way connected with the grinding plates or with any part subject to heavy wear.
The life of the lining is governed by the nature of the material ground. Eighteen months seems to be a safe average.	The life of the lining is at least equal to that of the ball mill, but as the kominuter will grind at least 50 per cent more than a ball mill of equal size the wear per ton of finished product is obviously very much smaller.
As, however, the grinding-plates form a principal part of the ball mill, the relining of the mill involves the disconnecting of many of the main parts and takes a gang of men several days. The cost of relining is further increased by the fact that the plates must be partially finished, it being only possible therefore to use in them material which can be readily machined.	The relining of the mill is done with much greater ease and at much less cost, as all plates can be handled by one man and merely passed through the manhole, no disconnecting of the principal parts of the mill being necessary.
Since the grinding-plates form also the supporting plates, care must be exercised not to let them wear down too far or the balls will fall through the screens and dust casing.	The grinding-plates are not machined, which reduces the cost and permits the use in the plates of the material best suited for the purpose, irrespective of its suitability for machining. Since the drum itself forms the supporting plate, the grinding plates can be worn out completely Consequently very little metal is thrown away in the replacement of a lining.

Ball Mill.	Kominuter.
Rejected materials return to the mill by gravity through perforated plates at each angle of the polygon. These plates extend the length of the mill. Assuming one third of the interior area to be covered with balls and material, this proportion of the return plates is of course under an outward pressure. Another third of the interior area is moving upward, and through this portion alone the rejected material must pass back into the mill. As the remaining third is moving downward, a portion of the material may move downward with it and thus remain on the screen. Consequently a considerable proportion of rejected material is carried around indefinitely at the periphery. If the mill is overfed, the insufficiency of the return openings results in choking the screens and limiting, if not altogether stopping, the screen action.	All materials fed to the kominuter must pass the full length of the drum under the grinding action of the balls, and is discharged through ports at the outlet end. The conical shape of the screens forces the material to move from the outlet end back to the inlet end, where the material rejected by the screens is caught by return buckets and returned to the inlet end of the drum by gravity. The buckets empty at the center of the mill around the shaft and above the level of the balls. It will thus be seen that it is impossible for any of the material to reënter the screens without repassing the grinding chamber, as may easily happen in the ball mill.
The discharge area in the ball mill is limited by the size and number of the holes in the perforated grinding-plates. The ball mill is not supplied with means for enlarging or reducing this discharge area. If the ball mill is fed with a material relatively fine and difficult of reduction, too large an amount will pass the perforations, overloading the screens and leaving too little material in the drum to be acted upon by the balls. Here the exit area is too large, and it cannot be readily reduced. On the other hand, if the ball mill is fed with a material easy of reduction, the balls will reduce more than the perforations and sieves can pass, resulting in an accumulation of an excess of finished material in the grinding-drum. Here the discharge area is too small, and it cannot be enlarged.	On the kominuter adjustments of the feed, of the discharge ports, and of the screens, are easily and quickly made. The total area of the discharge ports is greater than is required by the maximum charge of balls. It is an easy matter to insert a sufficient number of port closers, or covers, to allow the discharge of only sufficient material to utilize the extreme capacity of the sieves. With these three adjustments, the highest possible efficiency upon a given material may be promptly and easily secured.
A very large percentage of material which passes through the perforated grinding-plates has been ground small enough to pass the screens, but owing to the limited screen area it is returned to the mill and the power for regrinding is wasted. Twenty to twenty-five per cent of the material is thus reground unnecessarily.	The material discharged from the grinding-drum must pass over screens extending from the outlet end to the inlet end. The material refused by the screen in this travel is automatically returned to the inlet end of the drum. About one half of one per cent only of such returned material would have passed the screen.

A kominuter running on raw mix—a fairly soft, shaly limestone—gave a product of 15,046 lbs. per hour. The feed was coarse, varying from 4 inches down to dust, and would probably average 1½ inches. The product gave the following sieve test:

Mesh of Sieve.	Per Cent Passing.	Per Cent Residue.
10	99.5	0.5
20	95.0	5.0
30	75.5	24.5
50	57.5	42.5
80	45.5	54.5
100	43.5	56.5

Working on Lehigh district raw material, a kominuter has given over 14,000 lbs. per hour. On a harder mix, at a plant in the middle west, a kominuter gave 13,812 lbs. per hour.

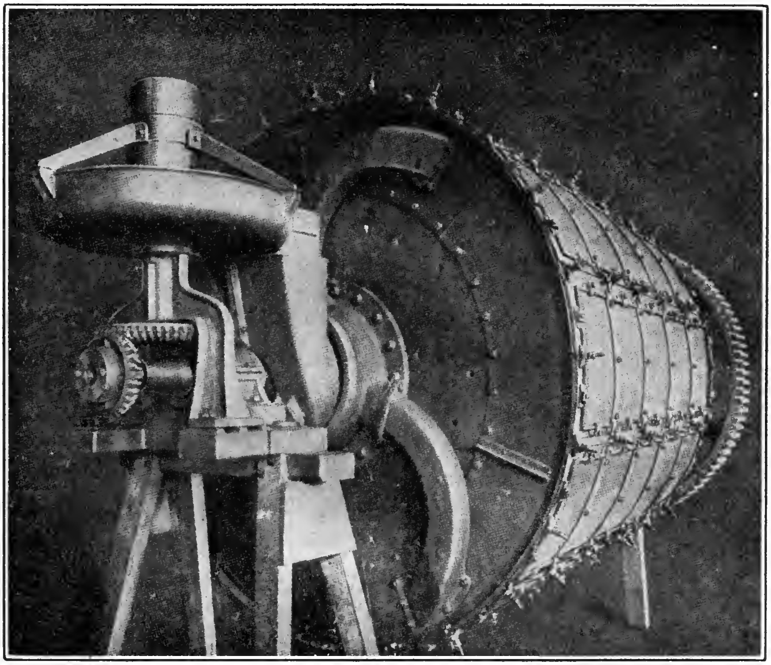


FIG. 98.—Exterior view of kominuter. (F. L. Smidth & Co.)

A kominuter running on a mixture of limestone and shale, of which the limestone had been passed through a crusher to, say, 1 inch, and the shale through a disintegrator, reduced about 18,000 lbs. per hour. The product on a number of sieve tests gave the following residues on a 100-mesh sieve:

54.5%, 55.2%, 59%, 52.4%, 43%, 45%.

A test run on clinker of a kominuter recently installed gave a product of 60 barrels per hour. The kominuter was fitted with 14-mesh screen and the product gave a residue of 55 per cent on a 50-mesh sieve.

Another plant using fresh clinker got a product of 35.3 bbls. per hour from one kominuter. This product gave the following results on a sieve test:

Mesh of Sieve.	Per Cent Passing.	Per Cent Residue.
20	95.5	4.5
50	56.6	43.4
100	31.3	68.7
200	20.0	80.0

At a third plant clinker averaging ½-inch size was handled by the kominuter at the rate of 15,114 lbs. per hour. The product gave the following sieve results:

Mesh of Sieve.	Per Cent Passing.	Per Cent Residue.
10	99.5	0.5
20	95.0	5.0
30	72.5	27.5
50	50.5	49.5
80	37.5	62.5
100	34.5	65.5

Ball mills.—Ball mills are now made by a number of manufacturers, the types most commonly found at the Portland-cement industry being the Smidth, Gates, and Krupp, and in wet-process plants, the Bonnot. Of these the Smidth ball mill is being gradually replaced by the Lindhard kominuter, and is now recommended by its manufacturers only for coal-grinding. It will therefore be omitted here and described on pages 516–519.

The wear of steel balls in ball mills working on clinker will vary usually between the limits of $\frac{1}{10}$ and $\frac{1}{25}$ lb. per barrel cement. As the balls at eastern points cost about $120 per ton, the cost per barrel will therefore range between ¼ and ½ cent.

Gates ball mill.—This mill is described by its makers as follows:

"The Gates ball mill consists of two circular side plates provided with inwardly projecting and eccentrically located shelves. The side plates have rigidly attached to them at their centers hubs which are mounted on a heavy shaft which revolves in dust-proof bearings. One of the hubs has suitable openings through which the material is automatically fed by the Gates patent feeder.

"Resting on the inwardly projecting shelves and reaching from one side plate to the other and bolted thereto are the wearing-plates. These are eccentrically arranged so that one plate passes behind the next one, thus producing a step and also providing an opening through which residues from the screens are returned to the mill. The tumbling of balls and material due to revolving the drum rapidly reduces the material to fine grit and powder, the steps serving to greatly increase the beating action of the balls against the material.

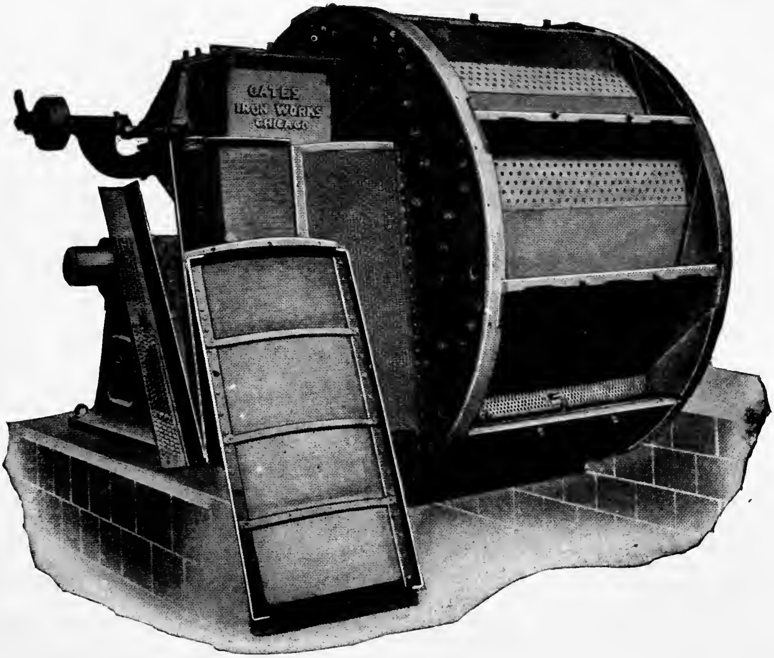


Fig. 99.—Gates ball mill with feeder attached (Allis-Chalmers Co.), showing grinding-plates in position and all other screws removed.

"When partially reduced, the ground product falls through apertures in the wearing-plates onto the first screen. The rejections from this screen are promptly returned to mill through the openings between the overlapping plates; the screened material falls upon the second screen and the rejections from it are likewise returned to mill, while the fines go to the outside finishing screen, and what passes through falls into the dust-proof housing and is removed by conveyor or other means for final pulverization; the residues join those of the other screens and with them are returned to the mill and subjected to further grinding action of the balls until fine enough to pass the outside or finishing screen."

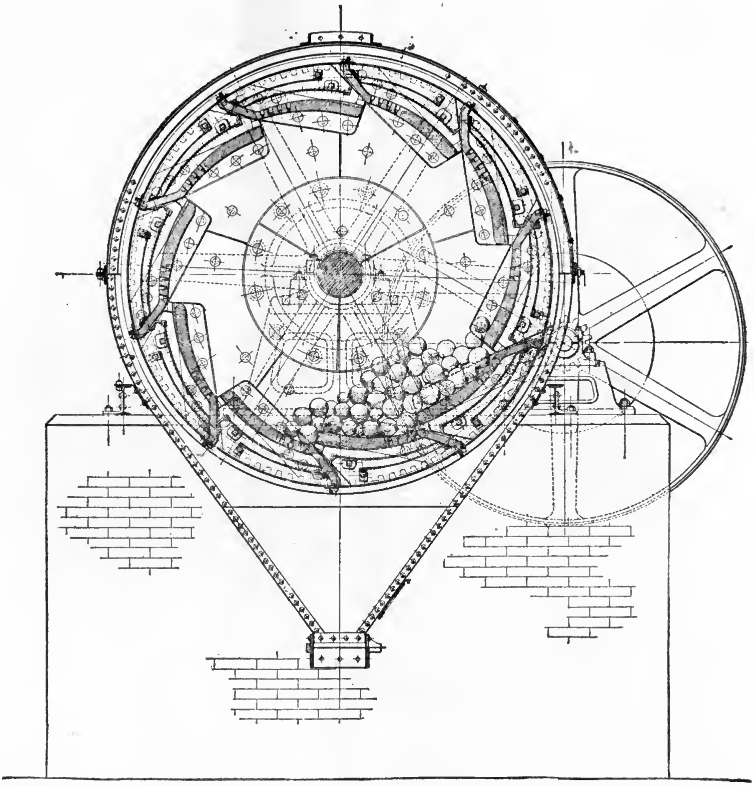


FIG. 100.—Transverse section of Gates ball mill. (Allis-Chalmers Co.)

TABLE 179.

SIZES, WEIGHTS, ETC., OF GATES BALL MILLS.

Size, Numbers.	Weight without Charge Balls.	Weight Charge of Balls.	Capacity on Portland-cement Clinker to 20-Mesh.	Power Required.
7	29,500 lbs.	3000 lbs.	12 to 16 bbls. per hour	30 to 40
8	41,100 "	4500 "	18 to 24 " " "	40 to 50

NOTE.—From 100 to 120 per cent additional power is required momentarily in starting the above machines. When pulverizing to pass all through 20-mesh from 30 to 40 per cent will pass a 100-mesh sieve.

Krupp ball mill.—This mill is described as follows by its agents:

"The Krupp ball mills are made in twelve different sizes, but for cement purposes in this country the size known as No. 8 has been uniformly adopted.

"The mill comprises essentially a cylindrical grinding-drum mounted on a hammered steel shaft running through it and provided with a dust-proof sheet-iron casing. The main shaft is carried on bearings secured to heavy bedplates bolted to a masonry foundation. The grinding-drum is composed of overlapping cast-steel plates (grinding-plates). The sides or head-walls of the drum are of wrought iron, secured to the main shaft by means of naves and lined with steel side-plates.

"The grinding-plates are strengthened on one half and bent inwards, and in the other half holes are bored and a series of blades or scoops (return scoops) of sheet iron, directed outwards, is provided. At those places where the scoops overlap, channels are left extending right across the whole breadth of the drum and partly stopped by low protection sieves arranged radially on the scoops.

"The drum is surrounded externally by a fine cylindrical sieve located at a certain distance from the grinding-plates. This sieve is constructed of a number of frames connected together and secured to angle-iron rings, forming the outside limit of the sides of the drum.

"The sieve frames are supplied in wrought iron. The sieves are covered by a phosphor-bronze or steel-wire gauze; the mesh is adapted to the required degree of fineness of the product desired.

"To protect the fine sieves, a coarse inner or fore sieve is arranged between the outer sieve and the grinding-plates. This inner sieve is constructed of finely perforated steel plates secured to the lateral flanges of the grinding-plates and to the back of the scoops; in front of the latter and across the whole breadth of the drum apertures are left.

"The drum contains a charge of Krupp special forged steel balls of various sizes and of a certain specified weight.

"The material is fed into the drum through a hopper secured to the nave at the front end of the drum. The nave itself is designed so as to form two peculiar slanting spokes which act as a screw conveyor and prevent the balls from being thrown out of the mill.

"The lower part of dust casing of the mill serves also for collection and discharge of the product ground and is provided with an outlet closed by a slide.

"In the larger mills a rectangular aperture is provided at the top of the dust casing for the purpose of connecting the mill with an air-shaft arranged above. The connection is made by means of a canvas hose secured to the dust casing by a wooden frame and clamping-screws. The current of air created in the shaft carries off the moist vapors arising during the grinding process, prevents dust flying from the feed-hopper, and likewise prevents the mill and material being ground from becoming unduly warm. In order that the current of air may be regulated according to the weather it is advisable to fit a damper in the shaft.

FIG. 101.—Automatic ball-mill feeder. (Smidth & Co.)

"Those parts of the mill which are subject to wear and tear, i.e., the balls, grinding, and side-plates, are made of extremely resistant well-tested material, so that the wear and tear is reduced to a minimum.

"The various parts of the mill may be readily renewed. For this purpose a manhole closed by a wrought-iron cover is provided in the side of the drum opposite to the hopper, so as to admit of easy access to the interior.

"The No. 8 mill will take pieces up to 6 inches in diameter, but the feeding device usually used is designed to take material up to 2½ inches only, which is as large as required for cement purposes in this country.

"In grinding, the balls in consequence of the peculiar arrangement of the grinding-plates, on rotation of the drum not only fall on the plate and roll forwards, but also fall over one another, whereby the material is rapidly broken up and finely crushed. After being thus ground for a sufficient time, the material falls through the apertures of the grinding-plates onto the inner or fore sieves, from this onto the fine sieves and through this finally, completely ground, into the lower part of the dust casing, whence it is discharged through the outlet. The material not yet sufficiently ground, and retained by the inner or the fine sieve is carried back by the return scoops into the drum for further grinding. This method of working gives rise to very little dust, as the material being ground as soon as it is sufficiently finely crushed, is immediately discharged automatically."

A Krupp 5′×21′ ball mill, run on ½-inch clinker, gave a product of 7914 lbs. per hour. This product showed sieve results as follows:

Mesh of Sieve.	Per Cent Passing.	Per Cent Residue.
10	100.0	0.0
20	99.5	0.5
30	84.5	15.5
50	57.0	43.0
80	39.0	61.0
100	36.0	64.0

Tube mills.—Unlike the ball mill, the tube mill has been an unqualified success as a fine grinder. Several manufacturers have placed these mills on the market, those most generally used being the Davidsen (F. L. Smidth & Co.), the Gates (Allis-Chalmers Company), the Krupp, and the Bonnot. The latter is rarely used in dry-process plants, but is common in wet plants.

The following description of the tube mill, published by the manufacturers of the Davidsen type, contains much of interest on the group in general.

"*Davidsen tube mill.*—The tube mill is simple, effective, and economical in both operation and maintenance. It consists of a wrought tube mounted as a shaft by the attachment of dome-shaped ends so formed as to make shafts, which rest in bearings at both ends. A large gear attached to the tube and a pinion attached to the pulley-shaft make the actuating device. The tube is lined with stone or chilled iron, as may be required, and the tube is about one-half filled with flint balls. The enormous grinding surface thus provided permits of a very slow speed of operation—27 turns per minute. The shaft at the feed end is hollow and a screw conveyor carries in the material. By simply regulating the feed any degree of fineness, even to impalpable powder, may be attained.

"Careful experiments have proved that for coarse grinding in a non-continuous mill, such as an Alsing drum, the highest efficiency is obtained from a charge consisting of a large mass of the material to be ground with a relatively small amount of flint balls, and that the highest efficiency in fine grinding results from the charge of a small mass with a large number of flint balls. Take, for example, a charge in the Alsing drum of a small proportion of balls to a large proportion of material. Up to a certain degree of coarseness the grinding will proceed rapidly with such a charge, but beyond that point to secure a high degree of fineness would require a proportionately very much longer working of the materials. Consequently any non-continuous working machine for pulverizing material is both unsatisfactory and expensive.

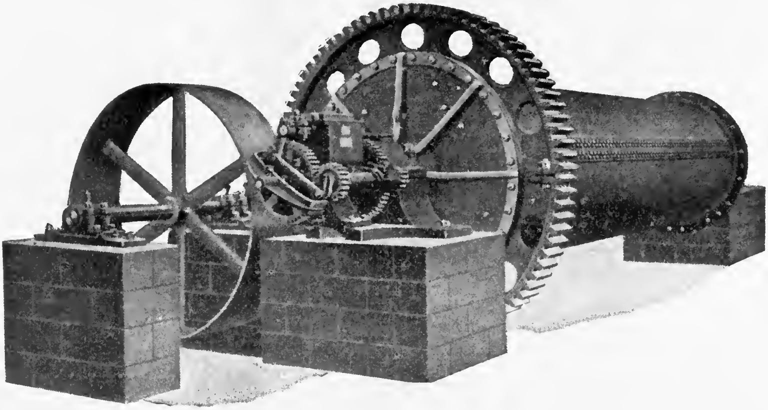


Fig. 102.—Gates tube mill. (Allis-Chalmers Co.)

"In the tube mill this principle has been taken advantage of; the flint balls bear a progressive ratio to the mass of material best adapted to the conditions demonstrated in the original experiments.

"The material to be ground is fed in at the center of one end of the tube mill, and is delivered, ground, at the periphery of the other end. The material consequently travels in a vertical line from the center to the circumference of the mill, and in a horizontal line from one end to the other. The tube mill being mounted horizontally, a longitudinal section, if taken when the mill is at rest, would show the material in the shape of an acute-angled triangle, with point at delivery end and base at the inlet; the transverse section at the inlet will, therefore, show a large amount of material to a small amount of flint balls, and a transverse section at outlet end would show the mill half full of flint balls, with but a small amount of material extremely finely ground. Between these two points there is a progressive disposition of the balls and material, but at the same time the flint balls are evenly distributed throughout the tube. Applying the principle enunciated above it will be seen that the coarse grinding is accomplished where the proportion of material is great in relation to the flint balls, and that the mere fact of delivery at the periphery of the other end compels an automatic and gradual adjustment of relations between balls and materials, so that at the delivery end a transverse section would show the mill half filled with balls with but a small portion of material subject to the grinding action.

"The speed at which the tube revolves tends to carry the mixture of balls and material to a certain height in the mill from which point balls and material fall together rolling and grinding as they seek the bottom of the mill; the action might be likened to the action of water at the crest of a wave. This sort of action can only take place when the mill has been half filled with the flint balls; if less than a proper charge of flint balls is used the whole mass has an inclination to only slide upon the inner surface of the tube, and none of the turbulent wave-crest action suggested takes place. Of course, much the best grinding is accomplished through keeping the whole mass of material grinding and pounding.

"The tube is lined with iron, specially made tiles, or a natural stone which we have named 'Silex.' These are set with Diamond cement made only for this purpose. Any bricklayer can readily lay up a lining.

"The life of a lining depends upon the character of the materials ground on it. With ordinary care all linings should last at least a year. In most cases linings have served eighteen and twenty-four months. Experience with Silex indicates that it will serve two or three years of continuous grinding.

"Experiment has proven that for grinding, flint balls are positively the most economical medium. The tube mill has therefore been designed for and proportioned for the use of flint balls.

"The tube mill for grinding slurry or wet materials is designed to use steel balls instead of flints, and is proportionately heavier in construction.

"It is absolutely necessary that the tube mill should be filled up to the center line with the flint balls; there is, consequently, no interior shaft. The tube revolves upon stub shafts, which are firmly anchored to the dome-shaped ends, the one at the inlet end being hollow, and through which the material is fed.

"The fact that flint balls in a tube mill represent an extraordinarily large grinding surface, makes it possible to run the mill at a slow speed so that all the power required is actually made use of in the grinding process itself and nothing is wasted in maintaining a high speed of machinery, which effects nothing in the grinding process itself.

"The fineness of the output is regulated by the speed at which the material is fed into the machine. As every particle of the material fed must pass under the grinding action of the entire charge of balls, a thorough and uniform grinding is bound to be the result; in fact, in practice it is found that the uniformity of the output is so great that it is unnecessary that sieves should be used, and no provision is made in the machine by which they can be used. There is, of course, nothing to prevent the materials being sieved, if it is desired, but this is absolutley useless when there is regularity of feeding. At a slow rate of feeding any required fineness can be obtained with any grindable material. The requirements for grinding Portland-cement clinkers are ordinarily that no more than 12 to 15 per cent residue shall be caught on a No. 200 sieve; when the tube mill is fed with coarsely ground product it will turn out from 8 to 16 barrels per hour of Portland-cement ground to the required fineness. However, these figures do not represent fully the value of the grinding capacity of the tube mill. Careful scientific investigation has proved that the fine product from the tube mill, which will pass sieve No. 200, contains 50 per cent more overfine particles than is the case in the output from any other existing grinding-machine.

"The foundation may consist of any material which will support the dead weight and enable the journals to be held firmly enough to withstand the tension of the driving-belt. In practice, however, it is, of course, preferable that the pedestal foundations should be deep enough in the earth to resist the action of frost, and should be made of permanent material, such as brick, stone or concrete.

"In the matter of repairs in this machine, as in others, the advantage of slow speed over high speed is practically noticeable. This principal wear is, of course, upon the flint balls, and by merely dropping in a few at stated intervals, to maintain the charge at its original bulk, the principal results of wear are made good at once.

"The flint balls, or pebbles, are a natural product; they are found

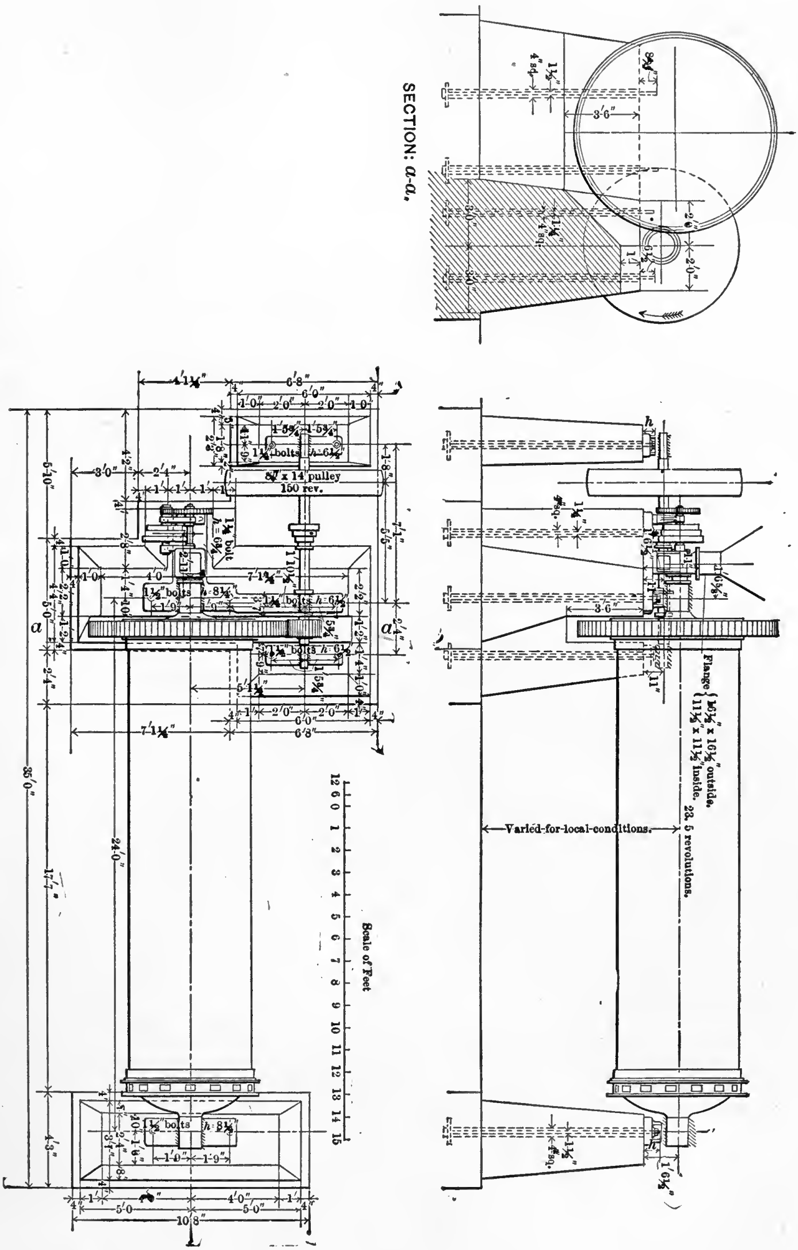


FIG. 103.—Setting of Davidsen tube mill (No. 16).

in certain parts of Europe and are comparatively inexpensive and of extraordinary hardness. It is the combination of these qualities that makes them preferable to the steel balls, even to the extent of building the mill four times as large as would be required with the steel balls. These flint balls are sold in four different sizes. The mill is originally charged with all four sizes in a set proportion, but replacements are always made with the largest size, as in practice the smaller pebbles seek the outlet end, and replacements are made at the inlet end.

"On average Portland-cement clinker the pebbles wear at the rate of about 1 lb. to 30 barrels of product.

"Little or no harm follows the introduction into the mill of substances foreign to the intended supply, such as steel or iron. When such substances reach the interior of the mill they either become grinding mediums and remain in the mill to accomplish that work, or else they are ground by the action of the mill and pass out with the product. This result is so unlike that following the introduction by accident of a piece of hard material into crushers, rollers, buhrstones or like machines, where the grinding surface is of metal, emery or dressed stone, that this one fact recommends it promptly to the observing purchaser.

"Two sizes of the Davidsen tube mill are made:

"No. 16. Requires 60 H.P. and a floor space of 36 feet by 13 feet, and turns 25 revolutions per minute.

"No. 12. Requires 27 H.P. and a floor space of 29 feet by 11 feet, and turns 27 revolutions per minute.

"The tube mill is a pulverizer, not a coarse grinder.

"The '*grindability*' of materials, even of the same class, varies so widely that it is impossible to give more than a general idea of the capacity of the tube mill. As an index, however, it may be stated that the No. 12 tube mill will pulverize from 3500 to 6500 lbs. of Portland-cement clinker per hour, 95 per cent of which will pass 10,000 meshes per square inch, such clinker having been preliminarily ground to pass No. 20 or No. 30 sieve.

"The No. 16 has about two and one quarter times the capacity of the No. 12."

Krupp tube mill.—The Krupp tube mill is described by its agents as follows:

"The Krupp tube mill is a cylinder or drum 5 feet in internal diameter and 22 feet long between the heads of the mill. This mill is so designed as to admit either silex or iron lining being installed.

"The feeding mechanism, the most accessible and most easily adjusted feeder on the market, is so designed that in making a change neither the mill nor the feeding mechanism is stopped so that an absolutely uninterrupted grinding action takes place. The main trunnion bearings are so designed as to admit of their being rebabbitted with the least possible lost of time and amount of labor.

"The mill is driven by means of a split-spur gear and pinion, the former being just scant of 10 feet in outside diameter. The discharge device is the Krupp patent cone discharge and includes all the advantages claimed for what is known as the peripheral discharge and also separates worn-out pebbles, and eliminates all the dust. The heads of the mill are of the strongest possible type, being conical in form.

"Every part of the mill is easily accessible, and all parts are made of the strength required for mills to be used in American cement practice.

"The capacity of the above mills, when working in battery, varies widely with the character of the material, varying as much as from 15 barrels per hour on a hard Portland-cement clinker to 60 barrels on a natural-cement clinker, the fineness of the product being 95 to 96 per cent through 100-mesh, 75 to 80 per cent through 200-mesh.

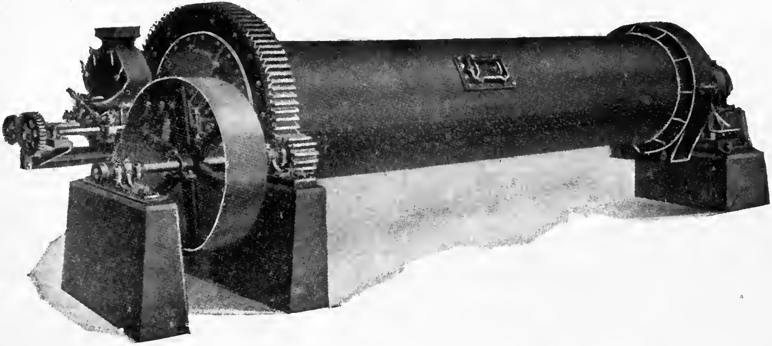


Fig. 104.—Exterior view of Bonnot tube mill. (Bonnot & Co.)

"The capacity on raw rock varies from 8 to 10 tons per hour, same fineness as mentioned for clinker.

"The capacity of the tube mill on coal varies from 3 to 4½ tons per hour, 90 to 95 per cent through a 100-mesh sieve."

Pebbles for tube mills.—For use in tube mills flint pebbles are the most satisfactory grinding materials. These are obtained chiefly from Greenland, Norway, Denmark, France, and England. Very little is in print concerning the flint industry, two recent papers of interest being listed below.*

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* Hill, R. T. Flint, an ancient industry. Eng. and Mining Journal, Nov. 7,

Concerning the French flints, Mr. Thackara writes as follows:

"By the action of the sea on the base of the chalk cliffs, which form the coast-line of a portion of the Department of Seine Inférieure, fragments of the rock are detached. Those which are composed of the flint found in the cliffs, on account of their hardness, are not reduced to sand by the trituration arising from the movement of the waves or tidal currents, and become what are known as sea flint pebbles. These are gathered on the beaches between Havre and St. Valery-sur-Somme, a distance of a little over 100 miles. Those which are nearly spherical in shape are carefully selected and are used in the Alsing system of cylinder grinding, which is becoming so generally employed for pulverizing cement, chemical and pharmaceutical products, etc. The others are bought by the potteries for making ordinary porcelain ware after being calcined, ground into a fine powder, and mixed with china clay.

"According to the official custom-house statistics, there were 13,592 tons of flint pebbles exported from France during 1900, valued at $39,348. The value of the declared exports of these stones from France to the United States for the fiscal year ended June 30, 1900, was $16,743, of which $3849 were shipped from Havre, $4458 from Boulogne, and $8436 from Dieppe.

"The prices of the flint pebbles for use in the potteries range from 5s. 3d. ($1.27) to 12s. ($2.92) per ton f. o. b. in bulk at Fécamp, St. Valery-en-Caux, Dieppe, Tréport, St. Valery-sur-Somme, and Havre, according to quality and to the port from which they are shipped. For the selected pebbles the prices vary from 35s. ($8.52) to 42s. ($10.21) f. o. b., packed in barrels or bags, packing included.

"The rate of freight from Havre or Dieppe to New York averages 10 francs ($1.93) per ton of 1000 kilograms (2204.6 pounds).

"French flint pebbles are shipped to England, Scotland, Norway, Sweden, Russia, Spain, Japan, and the United States. In the Baltic ports they have to compete with the pebbles exported from Denmark. Germany is now using silica sand from the river Rhine for pottery purposes, which replaces the flint pebbles. The French pebbles also have to compete with those collected on the English coast at Newhaven, Shoreham, and Rye, with the chalk flints shipped from London, and with the Greenland selected pebbles."

For the following analyses of tube-mill pebbles, from lots furnished by various importers, I am indebted to the chemists named below.

1903. Thackara, A. M. Export of sea flint pebbles from France. U. S. Consular Report No. 1231. Jan. 6. 1902.

TABLE 180.

ANALYSES OF FLINT PEBBLES.

	1.	2.	3.	4.	5.	6.	7.
Silica (SiO_2).	97.16	95.20	95.00	93.05	91.50	90.20	87.00
Alumina (Al_2O_3). . . . . . . Iron oxide (Fe_2O_3).	0.64	3.40	3.40	6.97	2.96	10.10	13.30
Lime (CaO).	0.22	1.35	....	....	2.92	n. d.	n. d.

1. Greenland. "Dana" brand. H. S. Turner, analyst.
2. Havre, France. light. Heiberg and Roney, analysts.
3. " " : dark. " " " "
4. St. Valerien, France: no. 1. " " " "
5. " " " : no. 2. " " " "
6. Norway: light. " " " "
7. " : dark. " " " "

From these analyses it will be seen what large variations in composition occur in different kinds of flint pebbles. Other things being equal, the pebbles highest in silica should give the best results, while lime is a particularly injurious impurity.

The high cost of flint pebbles for mills situated in the middle and western United States has led to many attempts to secure a domestic substitute for the expensive imported pebbles. Rounded pebbles of shape and character suitable for this use occur only on the shores of great lakes or along the beds of mountain streams. A California mill secures its supply from the American river, where rounded granite pebbles occur in quantity. These pebbles, gathered by Chinamen, cost less than $5.00 per ton at the mill, and are about half as durable as imported flints. For grinding 3000 barrels of cement, 800 lbs. of granite pebbles were used up, as against 400 lbs. of imported flint pebbles.

Flint occurs in several formations in America, but in no case do these formations outcrop along the shore, so that the flint can be obtained only in rough angular masses. Along the north shore of Lake Superior hard quartzite pebbles are said to occur in quantity, and this district may furnish a supply for the American cement trade if any manufacturer cares to investigate the matter.

Class 8. Impact Pulverizers.

The impact pulverizers include all those types of grinding-machines in which the material is broken by a blow, in free space, delivered by a series of rapidly revolving hammers, bars, cups or cages. This group therefore includes the Williams mill, the Raymond pulverizer, the Sturtevant and Stedman disintegrators, the Cyclone pulverizer, and many other less well-known devices. The Stedman disintegrator is extensively used in crushing gypsum or plaster and natural-cement clinker, and has, therefore, been already figured and described on pages 36, 37. Of the other impact pulverizers, the Williams mill is the only one extensively used in Portland-cement manufacture.

Raymond pulverizer.—Two Raymond pulverizers, one with three rollers and one with four, are in use at one plant, taking a dry limestone-and-shale mixture from dry-pans at about 30-mesh and reducing it to 98 per cent through a 100-mesh sieve. Each of these mills requires about 85 H.P., and delivers about 3½ tons of product (=11½ barrels cement). This seems to be a remarkably high figure for power, being equivalent to about 7½ H.P. hours per barrel, and it is probable that the pulverizer is not being run up to its true efficiency.

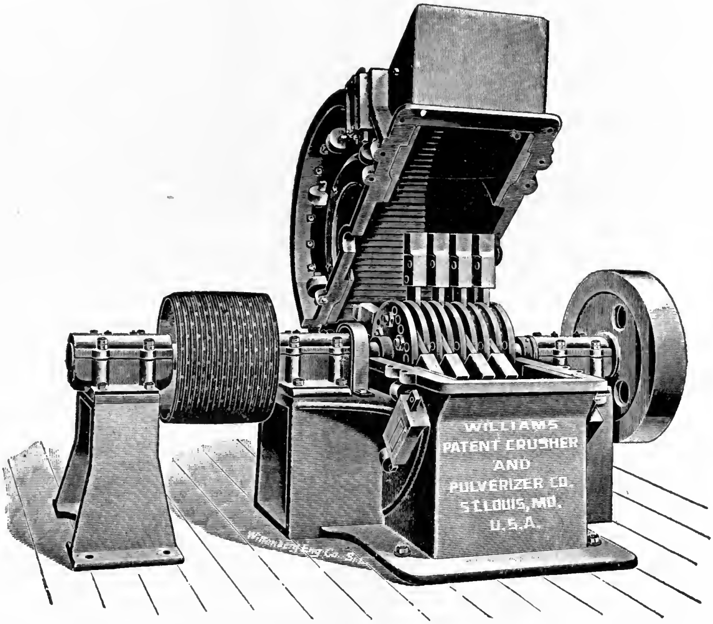

FIG. 105.—View of Williams mill, casing opened.

Williams mill.—The Williams mill is shown in view, with its casing opened, in Fig. 105, and in section in Fig. 106. It will be seen that it crushes by the blows of a series of hammers, rapidly revolving about a horizontal central axis.

The following record of an actual working test, communicated to me by the chemist of a plant using the Williams mill on its raw materials, will serve to show the percentages on different sieves that are produced by this mill. At the plant in question the materials used are hard limestone and shale. The raw materials are run through a Gates crusher, which gives a product averaging 1½ inches in size.

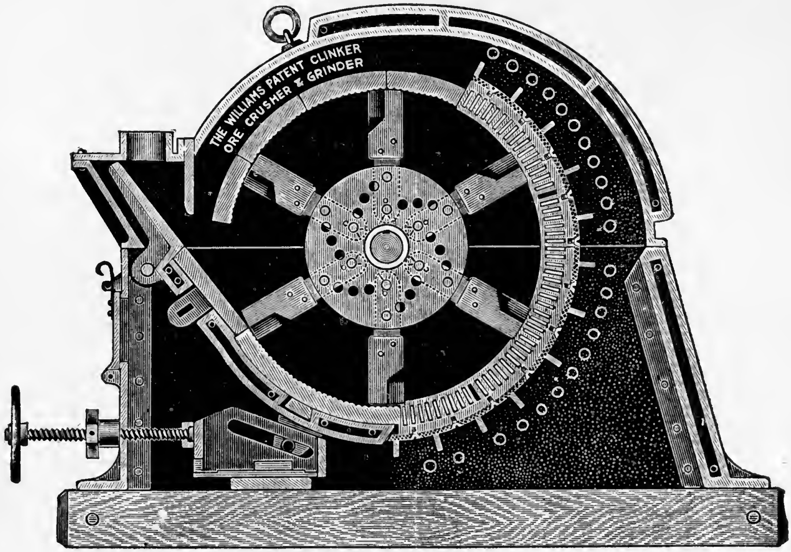

Fig. 106.—Section of Williams mill.

Three Williams mills, using about 18 H.P. each, take the product from this crusher and reduce it to give the following residues:

Mesh of sieve	20	50	100	200
Per cent residue	25	45.1	60.9	69.5
Per cent passing	75	54.9	39.1	30.5

The three Williams mills in use handle sufficient raw mix to give a production of about 1000 barrels per day. From these mills the material is fed to three tube mills, which take up 60 to 70 H.P. each, and complete the reduction so that 92 to 93 per cent passes a 100-mesh sieve.

Another test, for the record of which I am indebted to the manufacturers of the Williams mill, was carried on in a plant also using limestone and shale, crushed to about 1½ inch size.

Mesh of sieve	20	50	100	200
Per cent residue	26.8	51.3	68.7	76.0
Per cent passing	73.2	48.7	31.3	24.0

The writer has seen the Williams mill in operation at a number of Portland-cement plants, working on various raw materials and also on cement clinker. Its results when operating on shales, slates or thin bedded slaty limestone are remarkably good, and the machine appears to be particularly well adapted for such materials.

References on crushing machinery.—The following books and papers contain matter of interest in this connection, Richard's work being, of course, by far the most important:

Blake, W. P. The Blake stone and ore-breaker; its invention, forms and modifications. Trans. Amer. Inst. Mining Engrs., vol. 33, pp. 988–1031. 1903.

Fischer, H. The operator of a tube mill. Engineering and Mining Journal, Nov. 17, 1904, pp. 791–793.

Fraser, G. H. Recent results obtained with the Kent mill as a fine grinder. Cement, vol. 6, pp. 74–79. May, 1905.

Hutchinson, W. S. The plotting of sizing tests. Transactions Amer. Inst. Mining Engineers, 1904.

Lesley, R. W. The manufacture of cement. Trans. Am. Soc. C. E., vol. LIV, part B, pp. 89–130. 1905.

Richards, R. H. Ore Dressing. 2 vols, 8vo, pp. 1236. 1903.

Schwerin, M. Notes on some regrinding machines. Engineering and Mining Journal, Mch. 10, 1904, pp. 403–404.

Anon. The pebble tube mill in metallurgy. Electrochemical and Metallurgical Industry, vol. 3, pp. 41–42. Jan., 1905.

CHAPTER XXXII.

CEMENT BURNING: FIXED KILNS

The preceding chapters have been devoted to a discussion of the raw materials for Portland-cement manufacture, and to the processes and methods of preparing a mixture of these materials for the kiln. In the present and following chapters the next stage of the industry will be taken up—that of burning the raw mix into cement clinker.

Fixed or Stationary Kilns.

The earliest type of kiln used in Portland-cement manufacture was a simple vertical bottle-shaped kiln closely similar to those used in the burning of lime and natural cements. This was largely succeeded by improved types of stationary kilns in Germany and France, while in the United States the rotary kiln has become standard. Though stationary kilns are now very rare in American practice they have some undoubted advantages in localities where fuel is expensive and labor is cheap. As American engineers may soon have to consider the possibility of manufacturing cement in Central and South America, where these fuel and labor conditions are fulfilled, it has been considered advisable to discuss the improved type of stationary kilns in some detail. A list of references to the more important papers on the subject is also given at the end of the chapter.

In order that the relationships of the various types of fixed or stationary kilns may be clearly understood, it will be well to group them in classes according to the general principles on which their construction and operation are based. Four such groups can be formed:

1. Dome or intermittent kilns.
2. Dome kilns with drying accessories.
3. Ring or Hoffmann kilns.
4. Continuous shaft kilns.

These classes will be described in the order named.

1. Dome or Ordinary Intermittent Kilns.

All intermittent kilns will, for convenience, be here termed dome kilns, though the term is properly restricted to intermittent kilns of one particular shape.

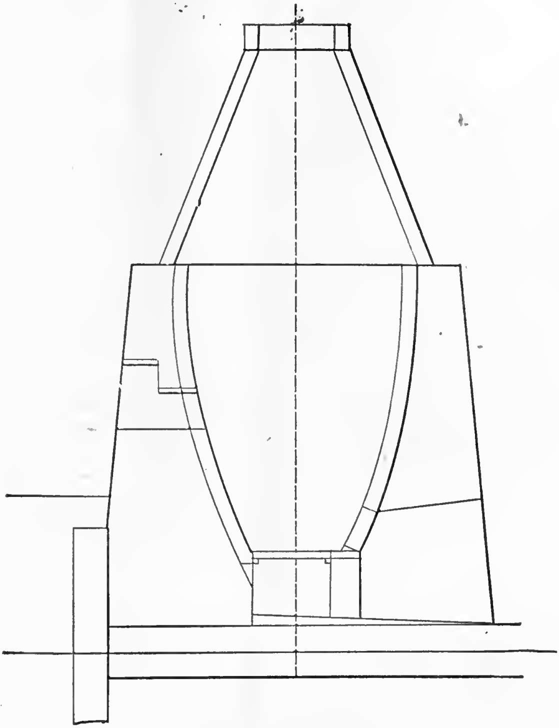

Fig. 107.—Dome kiln

The dome or bottle-shaped kiln is the original form on which most fixed kilns are based. As shown in Fig. 107 it is practically the shape of the older lime-kilns, differing usually in having a somewhat greater height for a given diameter. The type shown in the figure, which is the ordinary English form, is perhaps 9 to 12 feet in diameter at its widest portion, 15 to 18 feet from its base to this widest zone, and 25 to 35 feet in total height. This kiln is usually charged at several levels, one charging door being located a little below its widest point, and others being opened in the truncated cone which serves as a chimney.

In German practice these kilns assumed a form nearly like that of the blast-furnace. The body of the German dome kiln is usually a cylinder, 9 to 12 feet wide and 25 to 30 feet high. This is surmounted by a truncated-cone chimney, often high so that the total height of the kiln may be 35 to 75 feet. Candlot states that at some German plants kilns 22 feet in diameter and 100 feet in height were used, each of which kilns would turn out 400 tons (metric) of cement for each run.

Dome kilns are charged with fuel and mix, the latter in the form of bricks, in alternate layers, the proportions varying principally with the height of the kiln and the wetness of the bricks of mix. When the kiln is full the charging doors are closed and luted with fire-clay, and the lowest layer of fuel is ignited. As the burning progresses the entire mass settles, owing to the loss in fuel and carbon dioxide. The kiln may now be refilled to its former level, but nothing is drawn from it until the burning is complete, which may take from one to two weeks. Candlot states that the production of a dome kiln varies from ½ to 1 ton of clinker for each cubic meter of burning space, and that from 23 to 30 lbs. of fuel are required per 100 lbs. of clinker, the latter quantity varying according to whether anthracite, gas-coke, or oven-coke is employed. The labor cost of charging, drawing, and picking clinker from the dome kiln may vary from 30 to 50 cents per ton of cement, equivalent to about 5 to 10 cents per barrel.

2. Dome Kilns With Drying Accessories.

The first and simplest improvement on the primitive dome kiln was to provide each kiln with a drying tunnel. The kiln thus improved was still intermittent, but the drying tunnel gave a certain fuel economy, particularly when very wet mixes were employed. The principal type of this class of kiln is the Johnson kiln.

Johnson kiln.—The Johnson or chamber kiln was apparently the first English improvement on the simple dome kiln. It consists essentially of a dome kiln roofed over at the top, and with a long horizontal passage, semi-circular in section, opening into the kiln near the top and leading to a stack. The wet slurry is placed in the horizontal passage and dried by the hot gases passing through it from the kiln to the stack. The slurry when dry must be shovelled up and charged into the kiln by hand.

Various modifications of the Johnson kiln have been suggested and used in English plants,* most of them depending for extra economy on passing the hot gases under as well as over the slurry to be dried.

The Johnson kiln, with its different modifications, may be considered

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* Proc. Institution Civil Engineers, vol. 62, pp. 74–76. 1880.

essentially as combinations of old-style dome kilns and drying-floors. They utilize waste heat for drying the slurry; and are, therefore, more economical in fuel consumption than is the single-dome kiln. They are all based on intermittent working of the kiln, however; and in all, the dried slurry must be charged into the kiln by hand.

Six Johnson kilns were installed in 1890 at the plant of the Western Portland Cement Company, Yankton, S. D., but have recently been replaced by rotaries. I believe that similar kilns were used in the first plant at Whitecliffs, Ark.

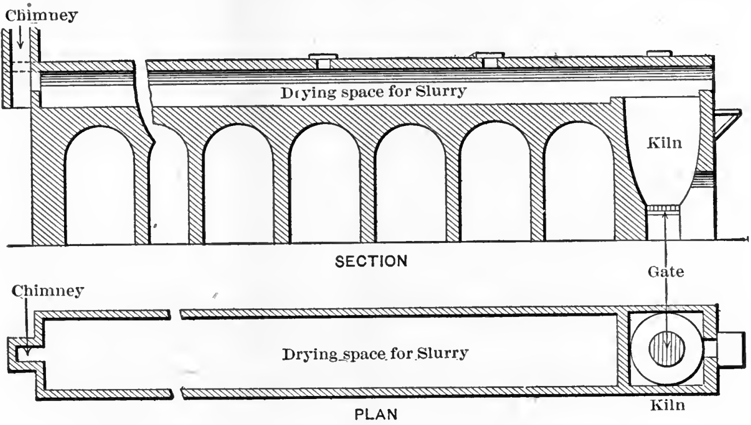

Fig. 108.—Plan and section of Johnson kiln. (Engineering News.)

3. Ring or Hoffmann Kilns.

The Hoffmann or ring kiln has been used quite extensively in Germany for burning Portland cement, lime, and bricks, but has never come into favor in either England or the United States. It consists essentially of a number of chambers arranged in a circle or ellipse around a central stack. Three flues lead from each chamber to (1) the central stack, (2) the chamber preceding it in the series, and (3) the chamber following it in the series. Each of these flues may be closed at will by the insertion of a partition of sheet iron. Each chamber also has a door opening to the outside of the kiln and used for charging and drawing.

Assuming that the kiln is entirely empty (a condition which could occur only in firing up a newly built kiln), the operations would be as follows: Each chamber would be loaded with bricks of dried slurry stacked up as in a brick kiln. Slack or other fine coal is fed in at the top of the chambers and one chamber is fired. All of the flues in the kiln leading to the stack are closed except one, i.e., the flue from the chamber *behind* the one which has been fired. All the inter-chamber flues are open except one, i.e., the flue between the fired chamber and the one immediately behind it in the series. The result of this arrangement is that the hot gases from the fired chamber pass in turn through each of the other loaded chambers until they arrive in the chamber immediately behind the fire, when they are passed into the central stack. The waste heat from the fired chamber is therefore utilized to the fullest extent in heating up all the other chambers.

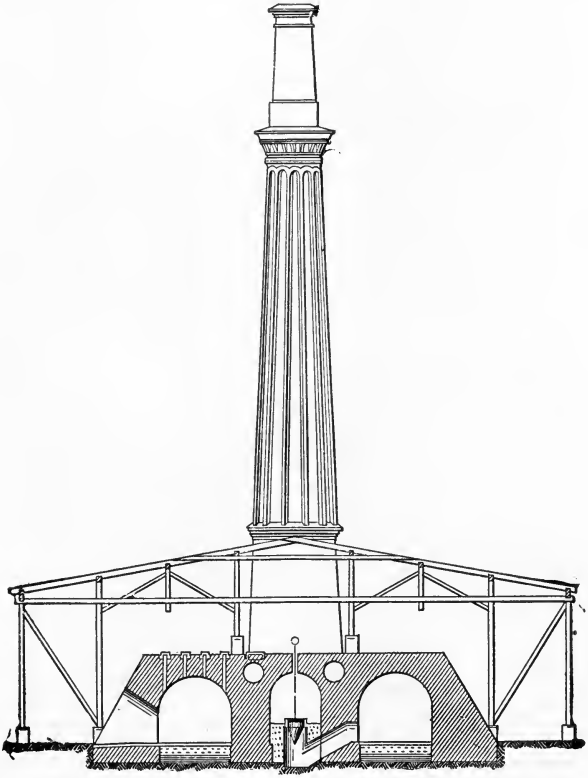

Fig. 109.—Section of Hoffmann kiln.

When the slurry in the fired chamber is converted into clinker this is allowed to cool. The chamber is then temporarily cut off from the rest of the series by closing its flues and the clinker is drawn. In the meantime the chamber next to it has been fired. The empty chamber is recharged and the flues to the central stack and *from* the chamber behind it are opened, thus making the newly filled chamber the end term of the series.

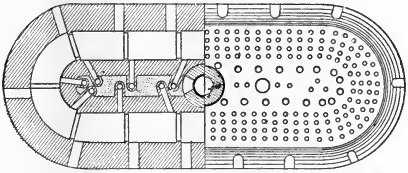

FIG. 110.—Plan of Hoffmann kiln.

As noted, the slurry charged into a Hoffmann kiln is necessarily in the form of bricks. The expense of partly drying the slurry and molding it into bricks must, therefore, be charged against the kiln. Taken as a whole the system is low in fuel consumption, but high in labor cost, especially since skilled labor is required for all the operations. Usually one chamber is loaded and one drawn each day. The output per kiln per day will, therefore, depend on the size of the chambers.

4. Continuous Shaft Kilns.

Dietzsch kiln.—In 1884 the Dietzsch kiln was first used in cement-manufacture, and its advantages soon became known. It has been in use at several American plants, and in the matter of fuel consumption is, perhaps, the best type of kiln that can be employed.

Dietzsch kilns are built in pairs, back to back, as shown in Fig. 111. They are 60 to 75 feet high, and consist of a cooling chamber at the base *D*, a fire-chamber or "creuset" *C*, and a preheating chamber *A*. It will be seen that these three parts of the kiln are not all in one vertical alignment, but that the axis of the preheating chamber, though parallel to the axis of the main kiln, is off to one side some distance, so that the two portions of the structure communicate by a horizontal passage *B*.

Aalborg or Schöfer kiln.—The Aalborg kiln, soon introduced in European cement practice after the success of the Dietzsch kiln had proven the possibility of economical continuous kilns, has been used at several American plants in a more or less modified form. The kiln is shown in section in Fig. 112. It will be seen that it is essentially the same as the Dietzsch, *except* that the preheating chamber, the burning space, and the cooling chamber are all in the same vertical line. This change, slight in appearance, economizes considerably in labor, for the charge descends of itself, without the rehandling necessary in the Dietzsch kiln. The mix is introduced through the charging opening *A*, while the coal is charged through the shutes (shown in the figure about an inch below *A*).

In European practice Candlot states that an Aalborg kiln will turn out 10 to 15 tons of clinker per day, with a fuel consumption of 280 lbs. coal per ton of product.

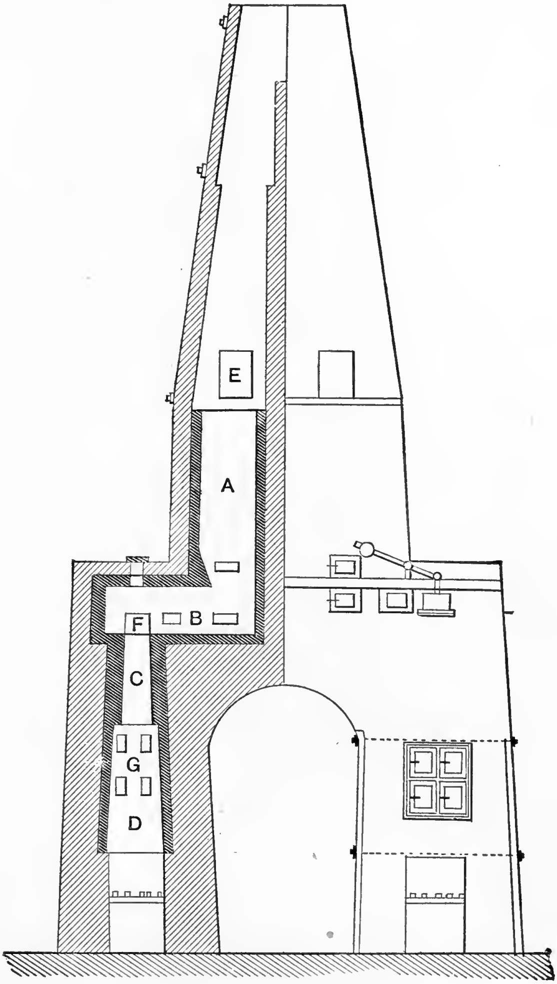

FIG. 111.—Dietzsch kilns.

Hauenschild kiln.—The Hauenschild kiln is a simple cylinder, charged at the top with both fuel and mix. It differs from a cylindrical lime-kiln only in having two distinct walls, with a space between. This annular space is used either for drying the mix or for heating the air to be supplied to the kiln. The result is that the interior lining is kept fairly cool, so that the charge does not clinker in masses against the walls,

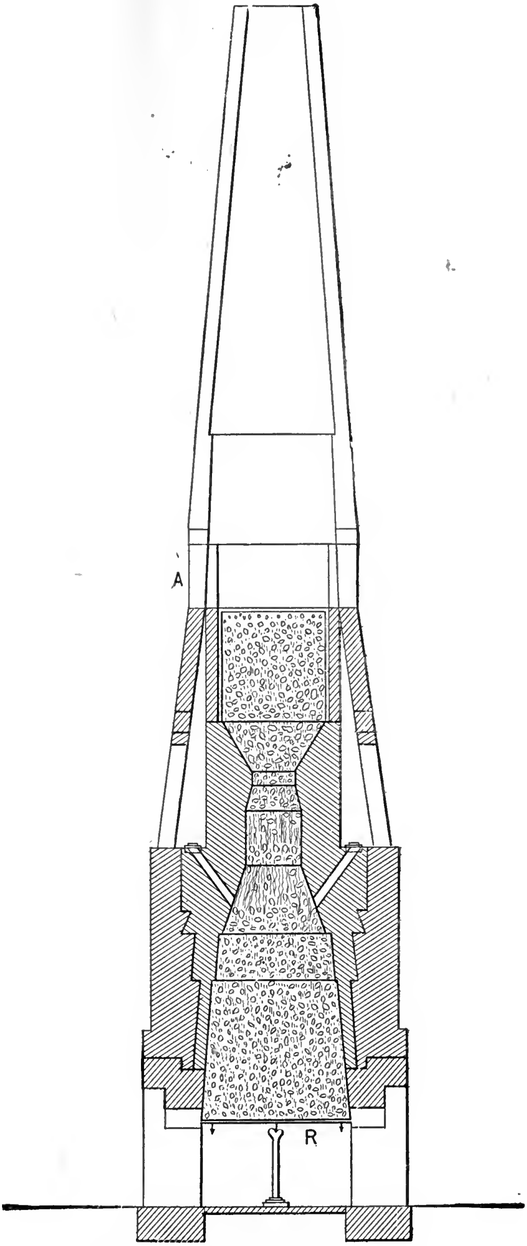

FIG. 112.—Section of Schöfer kiln.

which is the principal defect encountered in running a vertical kiln continuously.

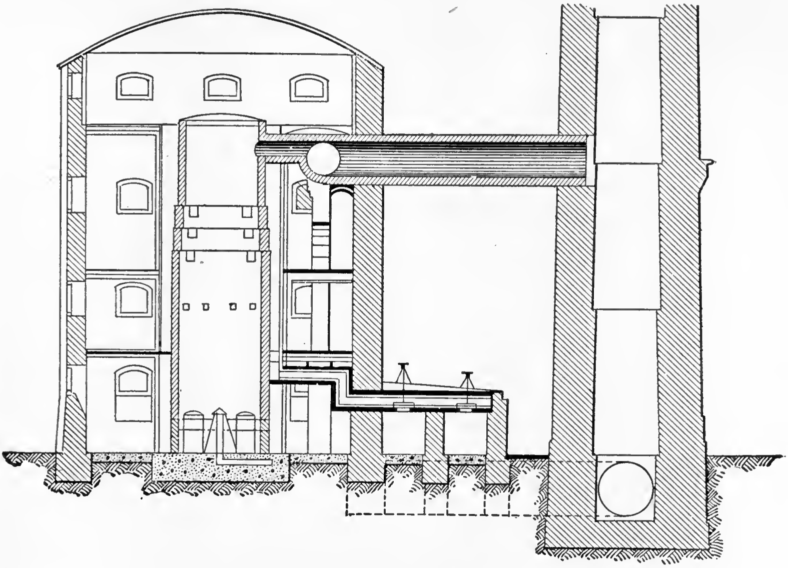

FIG. 113.—Hauenschild kiln.

Schwarz kiln.—In a recent paper on the manufacture of Portland cement from a mixture of slag and limestone C. von Schwarz describes a kiln used at a German cement plant. This kiln, here called the Schwarz kiln, is shown in partial section in Fig. 114. It is described as follows:

Each kiln consists, in its essential part of a series of rings, each 1 inch to 1½ inches in thickness, 8½ feet inner diameter, and 18 inches in height. These rings are provided outside with ribs, *r*, Fig. 112, and placed in such a way, one above the other, that the vertical ribs cover one another, thus forming little vertical channels *c*, *c*, *c* all around, in which the air circulates from below to the top, like in a chimney, thus continually cooling the cast-iron rings from the outside, and preventing them from getting overheated. The materials to be burnt are in direct contact with the cast-iron rings, no lining of any kind being provided for. There are 18 such rings, put one above the

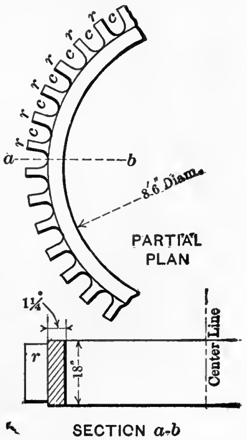

FIG. 114.—Partial plan and section of Schwarz kiln. (Engineering News).

other, the upper rings—where the greatest heat occurs—being hooped at the joints. The top of each kiln is provided with a cone and a chimney made of sheet iron, 3 feet in diameter and 30 feet in height. The cone has four charging doors, which can be closed by sheet-iron covers as soon as the charging is done.

At a depth of 12 feet from the top the inner diameter of the kiln is lessened to nearly half its inner horizontal section, and on this zone is provided with a double row of tuyeres to admit compressed air, this arrangement having for its object to burn any carbonic oxide or carburetted hydrogen gas arising from below as completely as possible, as well as to concentrate the heat exactly where it is required, viz., on the place where the formation of the clinker is to take place.

Compressed air is also introduced from below in two places. The pressed air is produced by a ventilator, the pressure being ¾ inch to 1¼ inches of water. One charge consists of 100 bricks and 65 to 70 lbs. of coke as fuel; one third of the coke could be replaced, if necessary, by anthracite or other small coal.

As a rule, four kilns are arranged in one set, being provided with a common elevator and a common platform, for all four kilns together. They are surrounded by a scaffolding made of angles and tees, on which the staircase to mount the platform is fixed. At the same time corrugated galvanized sheets are riveted on this scaffolding all round, in order to prevent unequal cooling of the furnaces outside in case of rain, wind, or snow.

The principal advantage of a kiln of this description is that, owing to the continuous and regular cooling from outside, the fritted clinker cannot clog the interior of the furnace, thus ensuring a regular and continuous working of the furnace. The ribs at the same time give strength, and prevent the cast-iron rings from warping. Each furnace produces about 25 tons of well-burnt clinker, equal to as much finished cement, in twenty-four hours.

Reference list for fixed kilns.—The design, construction, and operation of vertical or stationary kilns of various types are discussed in many books and papers on Portland-cement manufacture. The most satisfactory of these discussions are included in the following annotated list of references on the subject:

Butler, D. B. Portland Cement: its manufacture, testing, and use. 1899. Chapter IV of this volume, pp. 71–102, includes descriptions of the dome kiln, Johnson kiln, Batchelor kiln, Dietzsch kiln, and Hoffmann kiln. The discussion of the Johnson kiln and its modifications is particularly valuable.

Candlot, E. Ciments et chaux hydrauliques. 1898. Fixed kilns of various types are well described on pp. 53–71, inclusive.

Lewis, F. H. The Candlot oscillating grate for cement kilns. Engineering Record, May 21, 1898. Description of a grate devised to improve draft and prevent balling in shaft kilns.

Schoch, C. Die moderne Aufbereitung und Wertung der Mortel-Materialen. 1896. Pages 124–157 of this volume contain descriptions of various improved types of fixed kilns. Those of the Hoffmann, Dietzsch, Stein, Hanenschild, and Schöfer kilns are particularly valuable.

Scott, H. S. D., and Redgrave, G. R. The manufacture and testing of Portland cement. Proc. Inst. Civ. Engrs., vol. 62, pp. 67–86. 1880.

The Johnson kiln and its modifications are described in considerable detail on pp. 74–76.

Stanger, W. H., and Blount, B. The rotatory process of cement-manufacture. Proc. Inst. Civ. Engrs., vol. 165, pp. 44–136. 1901. Valuable data on the design, construction, and results obtained from various types of fixed kilns will be found on pp. 44, 48, 81, 82, 99, and 100.

Von Schwarz, C. The utilization of blast-furnace slag. Journal Iron and Steel Institute, 1900, No. 1, pp. 141–152. 1900. The Schwarz kiln is described with figures.

Zwick, H. Hydraulischer Kalk und Portland-Cement. 1892. Pages 148–184 are devoted to discussions of kilns and burning practice. The Hoffmann ring kiln is described in great detail.

CHAPTER XXXIII.

THE ROTARY KILN.

In the early days of the Portland-cement industry a simple vertical kiln, much like that used for burning lime and natural cement, was used for burning the Portland-cement mixture. These kilns, while fairly efficient so far as fuel consumption was concerned, were expensive in labor, and their daily output was small. In France and Germany they were soon supplanted by improved types, but still stationary and vertical, which gave very much lower fuel consumption. Kilns of these types have been discussed in the preceding chapter. In America, however, where labor is expensive while fuel is comparatively cheap, an entirely different style of kiln has been evolved. This is the rotary kiln. With the exception of a very few of the older plants, which have retained vertical kilns, all American Portland-cement plants are now equipped with rotary kilns.

FIG. 115.—Exterior view of rotary kiln. (Bonnot & Co.)

The rotary kiln as at first used in cement-manufacture was adapted to dry materials only, while gas or oil were used as fuel. A long series of experiments and improvements have perfected a burning process in which finely pulverized coal is used as fuel, while wet mixtures can now be fed directly to the kiln. The present condition, in which the rotary kiln is adapted to the use of several different types of fuel, and to all kinds of Portland-cement mixtures, has been attained only through long and earnest effort on the part of American cement-manufacturers.

The history of the gradual evolution of the rotary is of great interest, but as the subject cannot well be taken up here, reference should be made to the papers cited below,* which contain the details of this history, accompanied in many cases by illustrations of early forms of rotary kilns.

Summary of burning process.—As at present used, the rotary kiln is a steel cylinder, about 5 to 7 feet in diameter; its length for dry materials is 60 to 150 feet, while for wet mixtures an 80-foot or even longer kiln is commonly employed.

This cylinder is set in a slightly inclined position, the inclination being approximately one half inch to the foot. The kiln is lined, except near the upper end, with very resistant fire-brick, to withstand both the high temperature to which its inner surface is subjected and also the destructive action of the molten clinker.

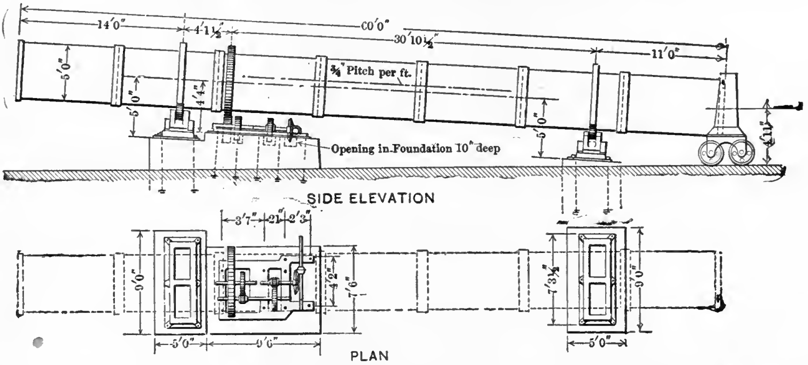

Fig. 116.—Plan and elevation of 60-foot rotary kiln. (Engineering News)

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* Duryee, E. The first manufacture of Portland cement by the direct rotary kiln process. Engineering News, July 26, 1900.

Eckel, E. C. Early history of the Portland-cement industry in New York State. Bulletin 44, New York State Museum, pp. 849-859. 1901.

Lesley, R. W. History of the Portland-cement industry in the United States. 8vo, 146 pp. Philadelphia, 1900.

Lewis, F. H. The American rotary kiln process for Portland cement. Cement Industry, pp. 188-199. New York, 1900.

Matthey, H. The invention of the new cement-burning method. Engineering and Mining Journal, vol. 67, p. 555, 705. 1899.

Smith, W. A. Manufacture of cement, 1892. Mineral Industry, vol. 1, pp. 49-53. 1893.

Stanger, W. H., and Blount, B. The rotatory process of cement-manufacture. Proc. Institution Civil Engineers, vol. 145, pp. 44-136. 1901.

Editorial. The influence of the rotary kiln on the development of Portland-cement manufacture in America. Engineering News, May 3, 1900

The cement mixture is fed in at the upper end of the kiln, while fuel (which may be either powdered coal, oil, or gas) is injected at its lower end. The kiln, which rests upon geared bearings, is slowly revolved about its axis. This revolution, in connection with the inclination at which the cylinder is set, gradually carries the cement mixture to the lower end of the kiln. In the course of this journey the intense heat generated by the burning fuel first drives off the water and carbon dioxide from the mixture and then causes the lime, silica, alumina, and iron to combine chemically to form the partially fused mass known as "cement clinker". This clinker drops out of the lower end of the kiln, is cooled so as to prevent injury to the grinding machinery, and is then sent to the grinding mills.

Shape and size.—The rotary kilns in use at various plants differ considerably in both shape and size.

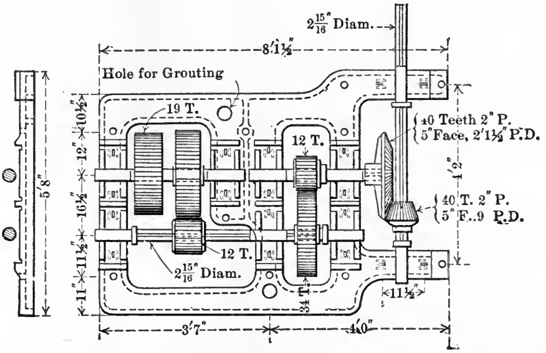


Fig. 117.—Driving mechanism of rotary kiln. (Engineering News.)

As to *shape*, the simplest and commonest form is that of a cylinder—a straight tube of equal diameter throughout. At many plants, however, the kilns are wider at the lower or discharge end than at the stack end. This is usually accomplished by means of a reducing section near the middle of the kiln, so that a kiln of this type would consist really of a lower section 6 feet in diameter and about 30 feet long, an upper section 5 feet in diameter and 30 feet long, and an intermediate reducing section in the shape of a frustum of a cone. The theory on which this arrangement is nominally based is that the gases, cooling as they near the upper end, should be confined in smaller space to keep up their efficiency. I am informed by Mr. Seaman, however, that the first kilns built in this way were made at the Atlas plant, during the early experiments, merely as a makeshift to utilize two 30-foot kilns of different diameters which happened to be on hand.

The variations in *size* are greater and more important than those in shape. Until within two years ago it could be said that the standard dry-process kiln was 60 feet in length and about 6 feet in diameter, while in the wet process the length ranged from 60 to 80 feet. These lengths had become well established in practice, soon after the rotary kiln list proved successful, and for many years it seemed as if practice had become fixed in this line at least.

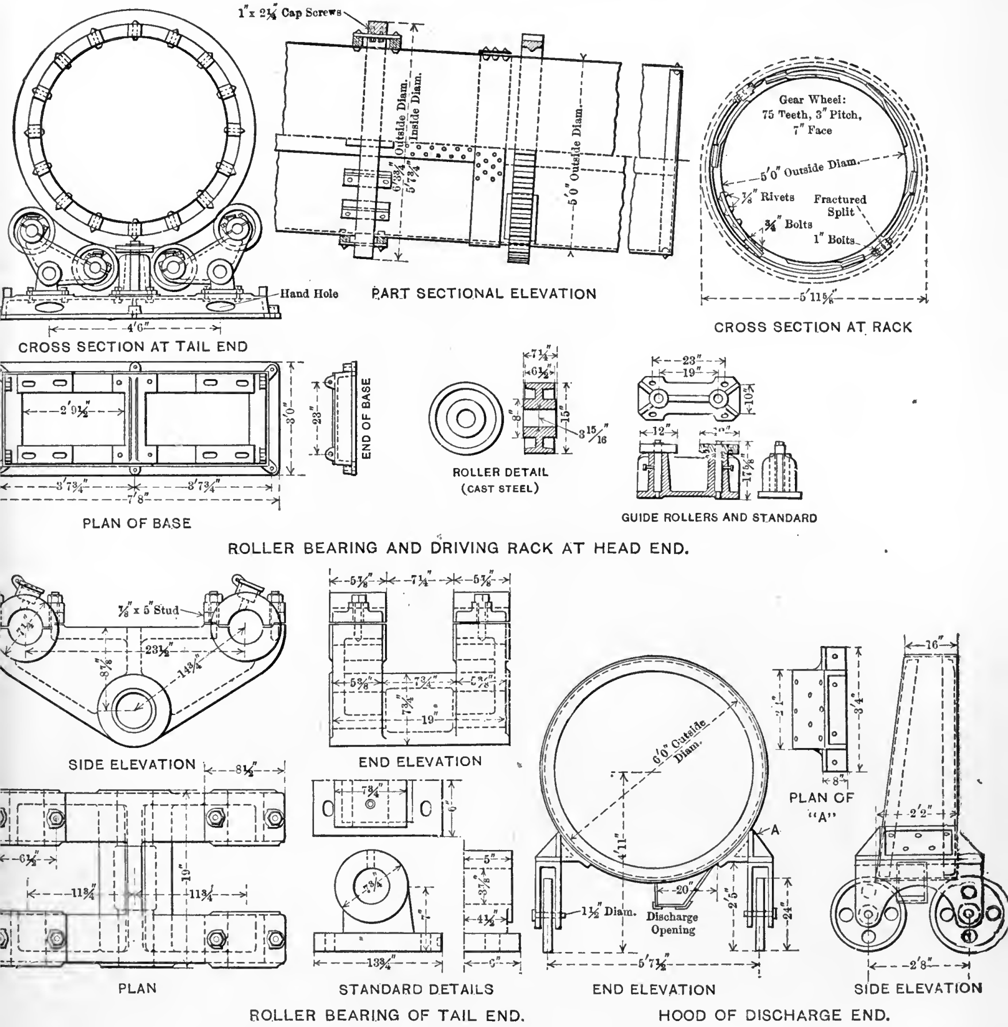


FIG. 118.—Details of 60-foot rotary kiln. (Engineering News.)

Several years ago Mr. Edison installed a 150-foot kiln in his New Jersey plant. The success attained by this kiln was masked for a time by defects in other portions of the plant's equipment, but as soon as it became apparent every manager in the United States began to consider the possibility of lengthening his kilns. The Edison kiln was reported to yield 350 to 375 barrels of cement per day, with a fuel consumption of only 65 lbs. of coal per barrel. Sixty-foot kilns, on the other hand, usually gave 160 to 180 barrels a day when working on a dry limestone-clay mix, and might use 110 to 150 pounds of coal per barrel. In the Lehigh district, working on the easily clinkered cement rock, results were better, but even here the maximum production could hardly exceed 225 bbls. per day, with a fuel consumption perhaps as low as 95 to 120 pounds.

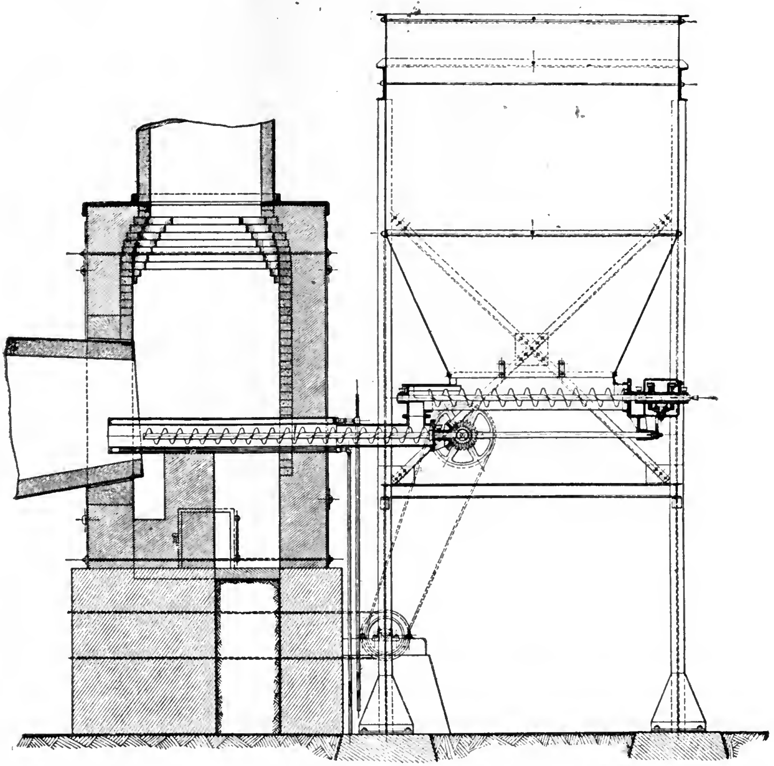


Fig. 119.—Raw material storage-bin, with adjustable feeder driven from kiln countershaft. (Allis-Chalmers Co.)

Such a contrast was too striking to permit much delay in lengthen-

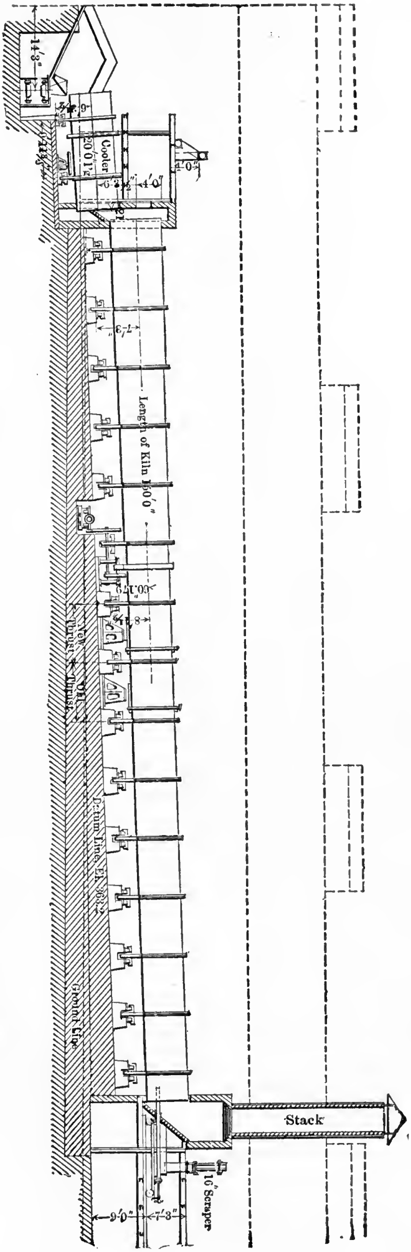


Fig. 120.—Longitudinal section of Edison 150-foot rotary kiln. (Engineering News.)

ing kilns, and at present kilns of 80 feet in length are common, while several of the best plants have installed kilns respectively 100, 107, and 110 feet long.

In the writer's opinion, however, the most remarkable development of recent years has been in an entirely different direction. Several plants in the United States are at present forcing their 60-foot kilns in such a way as to give over 300 barrels per day of good cement. This remarkable performance is not accompanied, it is true, by any saving in the amount of coal used per barrel; but even so, the production is worthy of note. The above statements as to production may be taken as accurate.

Feeding coal to the kiln.—In Figs. 121 and 122 is shown a typical coal-feeding installation, being one supplied by the B. F. Sturtevant Co. for the plant of the International Portland Cement Co., at Durham, Ontario. For the following description of this installation I am indebted to the manufacturers.

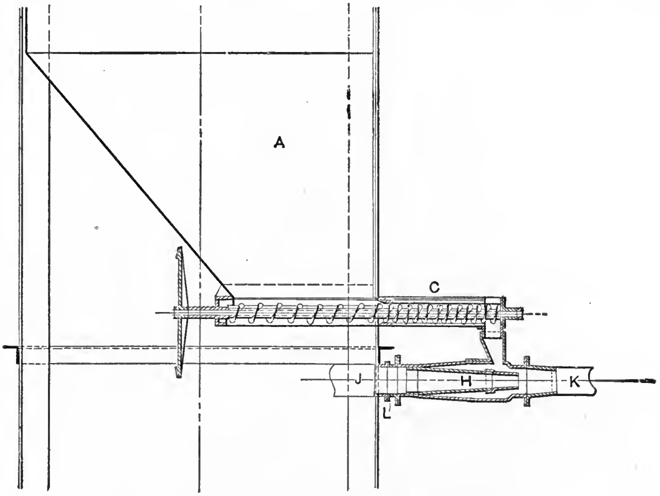
The coal is crushed, dried, and pulverized in the coal-house, located independently of kiln-room. It is very essential to the proper burning of the coal that it be well dried and pulverized. At least 88 per cent of the coal should pass a 100-mesh screen. The finer the coal is pulverized, the more advantageously can it be burned.

Pulverized coal is transferred from coal-house to storage-bins *A*, located directly in front of kilns, by means of an overhead-screw conveyor *B*, which discharges the pulverized coal into top of storage-bins. Each kiln has an independent storage-hopper which holds from ten to eighteen hours supply of pulverized coal.

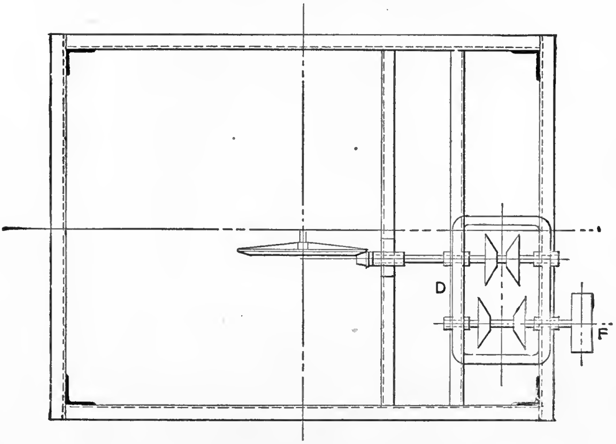
Pulverized coal is fed from the storage-hoppers into the injectors *H* by means of a small screw conveyor *C*, located at bottom of storage-bin, amount of coal handled by each injector being dependent upon the speed of the corresponding screw conveyor. The screw conveyor *C* is driven by a variable-speed machine *D* through a series of gears, so that the speed of the conveyor can be regulated according to operating conditions of plant, which vary to a great extent in most plants. The variable-speed machine is driven from a light-line shaft *E*, usually located on front of coal-hoppers. Pulley *F* on variable-speed machine is provided with a friction-clutch so that any unit consisting of kiln, storage-hopper, etc., can be shut down for repairs without interfering with the remainder of the plant.

For furnishing blast, two special gas-exhausters *G* are provided, each exhauster being of sufficient capacity to operate all injectors, the other exhauster being held in reserve in case of accident to the first.

The blast-fans are so arranged that the reserve fan could be placed in service in case of accident to the operating fan before kilns have time to cool to any great extent; after the kiln has cooled or when starting the kiln for burning clinker, it requires several hours to heat kiln to a proper temperature for the complete combustion of the pulverized coal. The blast-fans in most cases draw their supply of air directly from the kiln-room. In some plants, however, the inlet to blast-fans are connected with the clinker-coolers or the other parts of the



DETAIL ELEVATION OF FEEDING MECHANISM



DETAIL PLAN OF VARIABLE SPEED MECHANISM

Fig. 121.—Coal-burning arrangement, International Portland Cement Co. (B. F. Sturtevant Co.)

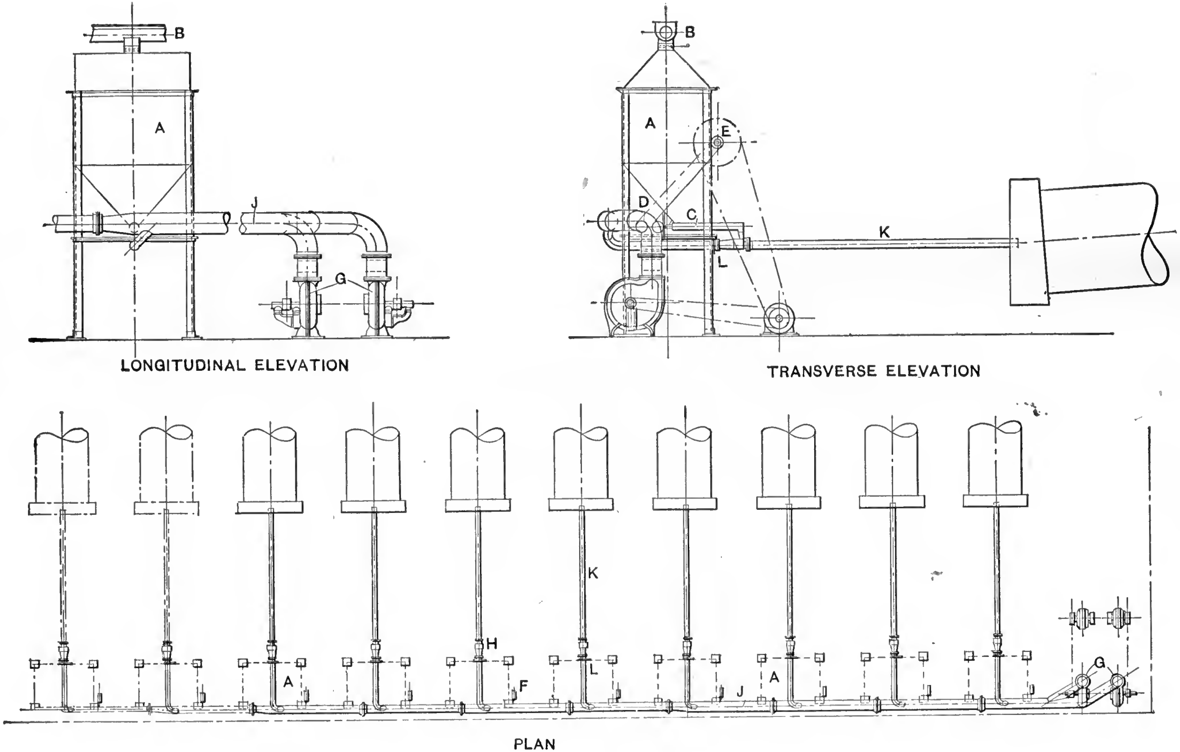


Fig. 122.—Coal-burning arrangement, International Portland Cement Co. (B. F. Sturtevant Co.)

cement apparatus, which have a tendency to heat large volumes of air by means of the galvanized steel ducts, thus insuring air at a much higher temperature for use as blast to the injector. The air-blast of fans is distributed to the several injectors by means of galvanized steel piping *J*, usually located directly in back of injectors.

The pulverized coal as it drops into injector is taken into suspension by air-blast supplied to injector through blast-piping *J* and fed through wrought-iron feed-pipes *K* into discharge end of kiln. The feed-pipe usually enters kiln about 3 to 12 inches below the center.

Fig. 123.—Kirkwood gas-burner for rotary kiln.

In extremely large kilns two feed-pipes are usually used so that current of air containing the pulverized coal can be blown into different points of the kiln at the same time. The volume of air admitted to injector is regulated by blast-gate *L*. The length of the flame in the kiln is dependent upon the velocity of the air as it leaves the feed-pipe.

Gas-burners for rotary kilns.—Natural gas is at present utilized as a kiln fuel at several Kansas plants. An Ohio plant when last visited was running some of its kilns on natural gas and some on producer gas. At all these plants the Kirkwood burner, shown in Figs. 123, 124, is used in supplying gas to the kiln.

The Kirkwood gas-burner is manufactured by Tate, Jones & Co., of Pittsburg, Pa., under patents granted to R. G. Kirkwood in 1896. It consists of two concentric cylindrical casings, which are bolted together, forming an annular chamber. A large number of small pipes are set to form a spiral series, passing from one side to the other of the annular chamber. These pipes are provided with a number of fine holes, and a nozzle caps the entire outfit. Gas is introduced through an opening into the annular chamber, from which it passes into the small pipes, issues through the holes in these pipes in a great number of fine jets and mixes with the air which is blown through the burner, thus securing a proper mixture of air and gas to be burned at the nozzle. A cast-iron plate filled with asbestos cement is provided for bolting to the front of the kiln to receive the end of the burner, and the back of the burner has a projection into which the air-blast pipe is introduced. These burners are about 18 inches in diameter and 5 feet in length, and are designed to work efficiently with a gas pressure of from 3 to 4 ounces per square inch.

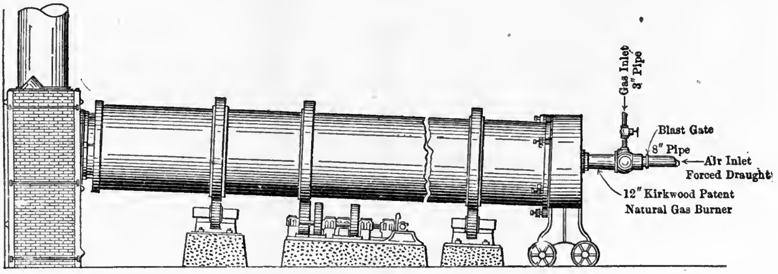


FIG. 124.—Kirkwood gas-burner applied to rotary kiln. (Tate, Jones & Co.)

Kiln linings.—Three materials have been used for kiln linings; cement clinker, alumina brick, and magnesia brick. A fourth will probably be introduced in the near future—bauxite brick.

Of these lining materials, the use of alumina brick may be considered to be the standard American practice. In the following tables analyses of these products are given. Table 181 contains analyses of clays used in the manufacture of high-alumina kiln brick, while analyses of the brick are given in Table 182. Tables 183 and 184 contain analyses of low-alumina clays and the resulting brick, which have been supplied for rotary-kiln linings at several plants.

TABLE 181.

ANALYSES OF HIGH-ALUMINA CLAYS USED FOR KILN BRICK.

	1.	2.	3.	4.
Silica (SiO_2)	4.338	44.52	43.05	40.30
Alumina (Al_2O_3)	40.35	40.81	44.60	45.00
Iron oxide (Fe_2O_3)	0.85	1.03	2.60	n. d.
Lime (CaO)	0.88	0.62	0.40	n. d.
Magnesia (MgO)	0.23	0.55	0.20	n. d.
Carbon dioxide (CO_2)	13.41	12.11	9.00	n. d.
Water				

	5.	6.	7.	8.
Silica (SiO_2)	40.80	42.71	44.00	43.52
Alumina (Al_2O_3)	49.00	38.88	42.12	42.18
Iron oxide (Fe_2O_3)	n. d	3.36	0.86	0.42
Lime (CaO)	n. d.	0.13	0.24	0.25
Magnesia (MgO)	n. d.	0.00	0.10	0.16
Carbon dioxide (CO_2)	n. d.	15.19	14.20	14.31
Water				

1, 2. Olive Hill, Carter County, Ky. Analyses from Stowe-Fuller Co.'s catalogue, p. 25½.
3, 4, 5. Hayward, Carter County, Ky. Ironton Fire-brick Co.
6. Carter County, Ky. Chas. Taylor's Sons. F. W. Clarke, analyst. Specimen selected by E. C. Eckel.
7. Lock Haven, Pa. P. L. Hobbs, analyst. Stowe-Fuller Co.'s catalogue, p. 26½.
8. " " , " Crowell and Peck, analysts. Stowe-Fuller Co.'s catalogue, p. 26½.

TABLE 182.

ANALYSES OF HIGH-ALUMINA FIRE-BRICK FOR KILNS.

	1.	2.	3.	4.
Silica (SiO_2)	54.86	52.64	49.70	54.03
Alumina (Al_2O_3)	42.74	44.84	47.86	40.45
Iron oxide (Fe_2O_3)				3.47
Lime (CaO)	1.30	0.84	0.80	0.31
Magnesia (MgO)	0.62	0.88	0.80	tr.

	5.	6.	7.	8.	9.
Silica (SiO_2)	55.22	54.38	58.90	51.95	56.44
Alumina (Al_2O_3)	41.51	41.72	36.30	45.01	35.81
Iron oxide (Fe_2O_3)	.....	2.84	3.20	2.01	4.79
Lime (CaO)	.....	1.00	1.60	0.04	n. d.
Magnesia (MgO)	.....	tr.	tr.	0.29	n. d.

1, 2. "Tyrone" brick, Harbison-Walker Co. H. S. Turner, analyst.
3. Kentucky Fire Brick Co. H. S. Turner, analyst.
4. Ironton Fire Brick Co. F. W. Clarke, analyst. Specimen selected by E. C. Eckel.
5. " " " " Analysis quoted by manufacturers.
6, 7. Christy Fire Brick Co.
8. "Munro" brick, Stowe-Fuller Co. P. L. Hobbs, analyst. Catalogue, p. 70.
9. Stowe Fuller Co. E. Davidson, analyst.

TABLE 183.

ANALYSES OF LOW-ALUMINA CLAYS USED FOR KILN BRICK.

Silica (SiO_2)	55.0	56.02
Alumina (Al_2O_3)	30.0	28.26
Iron oxide (Fe_2O_3)	tr.	2.18
Lime (CaO)	tr.	2.04
Magnesia (MgO)	tr.	0.95
Alkalies (K_2O,Na_2O)	2.0	n. d.
Carbon dioxide (CO_2) Water	13.0	10.50

TABLE 184.

ANALYSES OF LOW-ALUMINA BRICK, FURNISHED AS KILN BRICK.

	1.	2.	3.	4.	5.
Silica (SiO_2)	62.58	63.94	61.20	62.92	72.71
Alumina (Al_2O_3)	25.62	30.14	29.05	30.47	22.24
Iron oxide (Fe_2O_3)	4.76	3.70	5.55	4.61	4.47
Lime (CaO)	6.05	2.20	n. d.	n. d.	0.94
Magnesia (MgO)	0.85	tr.	n. d.	n. d.	0.42

The manner in which these bricks are set in lining kilns is shown in Figs. 125 and 126.

Actual fuel consumption and output.—In the following chapter the question of heat requirements and heat distribution in the rotary kiln will be discussed in considerable detail. At present it is only necessary to state that in burning a dry mixture to a clinker, practically all of the heat consumed in the operation will be that required for the dissociation of the lime carbonate present into lime oxide and carbon dioxide. Driving off the water of combination that is chemically held by the clay or shale, and decomposing any calcium sulphate (gypsum) that may be present in the raw materials, will require a small additional amount of heat. The amount required for these purposes is not accurately known, however, but is probably so small that it will be more or less entirely offset by the heat which will be liberated during the combination of the lime with the silica and alumina. We may, therefore, without sensible error regard the total heat *theoretically* required for the production of a barrel of Portland cement as being that which is necessary for the dissociation of 450 lbs. of lime carbonate. With coal of a thermal value of 13,500 B.T.U. per pound, burned with only the air-supply demanded by theory, this dissociation would require about 25½ lbs. of coal per barrel of cement, a fuel consumption of only 6½ per cent on the weight of cement produced.

In actual practice, however, the heat required for cement produc-

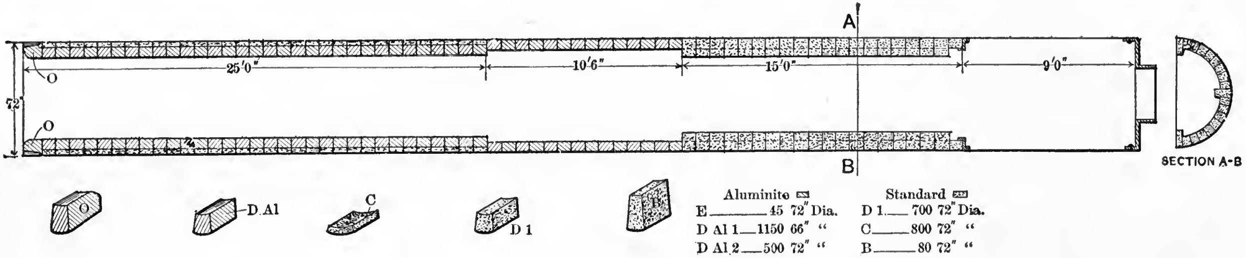


FIG. 125.—Arrangement of kiln lining, wet process. (Stowe-Fuller Co.)

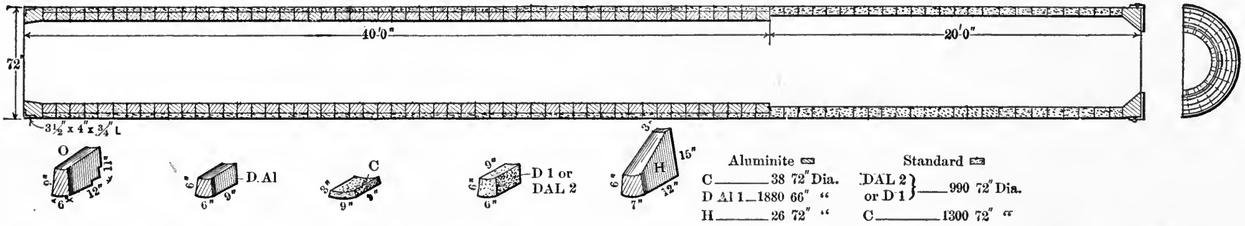


FIG. 126.—Arrangement of kiln lining, dry process. (Stowe-Fuller Co.) Asano Portland Cement Co., Tokyo, Japan.

tion is immensely greater than that demanded by theory. This is due to the fact that heat is wasted or lost in various ways during the process of burning in the rotary kiln. The more important losses of heat occur from the fact that the stack-gases and clinker are usually discharged at high temperatures; that the air-supply injected into the kiln is always greater, and usually much greater, than that theoretically necessary; and that much heat is lost by radiation from the exposed surface of the kiln.

Sixty-foot rotary kilns are nominally rated at a production of 200 barrels per day per kiln. Even on dry materials and with good coal, however, such an output is rarely attained. Normally a 60-foot kiln working on a dry mixture will produce from 140 to 180 barrels of cement per day of twenty-four hours. In doing this, if good coal is used, its fuel consumption will commonly be from 120 to 140 lbs. of coal per barrel of cement, though it may range as high as 160 lbs., and, on the other hand, has fallen as low as 90 lbs. An output of 160 barrels per day, with a coal consumption of 130 lbs. per barrel, may therefore be considered as representing the results of fairly good practice on dry materials. With longer kilns, however, much better results are obtained, as will be noted later.

In dealing with a wet mixture, which may carry anywhere from 30 to 70 per cent of water, the results are more variable, though always worse than with dry materials. In working a 60-foot kiln on a wet material, the output may range from 80 to 140 barrels per day, with a fuel consumption of from 150 to 230 lbs. per barrel. Using a longer kiln, partly drying the mix, and utilizing waste heat will, of course, improve these figures materially.

When oil is used for kiln fuel, it may be considered that one gallon of oil is equivalent in the kiln to about 10 lbs. of coal. The fuel consumption, using dry materials, will range between 11 and 14 gallons of oil per barrel of cement; but the output per day is always somewhat less with oil fuel than where coal is used.

Natural gas in the kiln may be compared with good Pennsylvania or West Virginia coal by allowing about 20,000 cubic feet of gas as equivalent to a ton of coal. This estimate is, however, based upon too little data to be as close as those above given for oil.

The figures given in Table 185, below, are believed to be entirely reliable. They are of interest as showing what can actually be expected from kilns under average management, as distinguished from the expectations which embellish company prospectuses and the reports of "cement experts." With the exception of A, B, and J, the mills here listed are good average plants. Mill results A and B are from one of the best of the Lehigh district plants, while J is perhaps the best of all marl-plants. Excluding these three, it will be seen that the production per kiln per day is considerably lower, and the fuel consumption much higher, than is usually allowed for.

TABLE 185.

ACTUAL OUTPUT AND FUEL CONSUMPTION AT VARIOUS PLANTS.

Mill.	Materials.	Process.	Per Cent of Water in Mixture.	Length of Kiln, Feet.	Output per Day, Barrels.	Coal per Barrel, Pounds.
A	Cement rock	Dry	..	60	225	105–113
B	" "	"	..	80	260	95–100
C	" "	"	..	60	160–180	109–175
D	" "	"	..	150	350	62–75
E	Limestone and shale	"	..	60	170	160
F	" " "	"	..	60	?	105
G	" " "	"	..	60	?	122
H	" " "	"	..	60	185	130
I	" " "	"	..	60	170	135
J	Marl and clay	Wet	60	110	135	?
K	Marl and shale	"	50	70	145	?
L	" " "	"	60	60	85	?
M	" " "	"	50	60	120	?
N	Marl and clay	"	30	60	125	173
O	" " "	"	35	60	100	160
P	" " "	"	65	60	80	180–210
Q	Limestone and clay	"	35	60	100	200–220
R	" " "	"	30	60	140	180

Using the figures above given as a basis, Table 185 has been constructed to give some idea of what may fairly be expected from kilns of various length working on different raw materials.

TABLE 186.

AVERAGE OUTPUT AND FUEL CONSUMPTION.

Process.	Raw Materials.	Length of Kiln, Feet.	Output per Kiln per Day, Barrels.		Coal Consumption per Kiln per Barrel, Pounds.	
			Range.	Average.	Range.	Average.
Wet	Marl and clay	60	60–140	85	150–250	200
"	" " "	80–90	80–150	100	140–220	160
"	" " "	110*	135	135	150	150
Dry	Limestone and clay	60	150–200	160	90–170	130
"	Cement rock and limestone	60	180–250	200	85–160	115
"	" " " "	80	225–300	260	85–120	110
"	" " " "	150*	375	375	65	65

* Based on only one plant.

The differences in composition between Portland-cement mixtures are very slight if compared, for example, to the differences between various natural cement rocks. But even such slight differences as do exist exercise a very appreciable effect on the burning of the mixture. Other things being equal, any increase in the percentage of lime in the mixture will necessitate a higher temperature in order to get an equally sound cement. A mixture which will give a cement carrying 59 per cent of lime, for example, will require much less thorough burning than would a mixture designed to give a cement with 64 per cent of lime.

With equal lime percentages, the cement carrying high silica and low alumina and iron will require a higher temperature than if it were lower in silica and higher in alumina and iron. But, on the other hand, if the alumina and iron are carried too high, the clinker will ball up in the kiln, forming sticky and unmanageable masses.

CHAPTER XXXIV.

HEAT CONSUMPTION AND HEAT UTILIZATION.

An investigation of the ways in which the heat supplied to the kiln is utilized and wasted is a matter of both theoretical and practical importance. It can readily be seen that until some idea can be gained of the relative importance of the different causes of loss of heat, little can be done to prevent this waste or to utilize the heat so dispersed. An exact knowledge of the distribution of the total heat supplied to the kiln would therefore be of great service to the manufacturer.

In the present chapter the writer has attempted to present such data on this subject as are available, and to discuss them in such a way as to bring out the relations of the various factors in the problem of heat distribution. Attention is drawn, whenever necessary, to any doubts as to the accuracy of the data employed.

Theoretical Heat Requirements.

In order that a raw mixture shall be converted into cement clinker in the kiln, sufficient heat must be applied to bring about the necessary physical and chemical changes. The purposes for which this heat is required are:

(1) Evaporation of the water of the mix.
(2) Decomposition of the clay.
(3) Dissociation of sulphates.
(4) Dissociation of carbonates.
(5) Heating the mix to clinkering point.

Of these five requirements, it is to be noted that the first four are for accomplishing chemical changes, and that the heat supplied for these purposes is entirely absorbed in doing chemical work. This is not true with regard to the fifth requirement—the heating of the mix—for the heat used for this purpose, after it has once served its purpose, still remains as sensible and therefore utilizable heat. Most of it, in fact, passes out in the clinker.

In a perfect kiln the only heat required would be that sufficient to accomplish the first four operations in the above list, for in a theoretically perfect burning device there would be no loss by radiation, the stack-gases would be cold, and the clinker heat would be utilized.

In actual practice, however, a very large amount of heat is carried out with the stack-gases, radiated from the exposed surfaces of the kiln, and carried out in the hot clinker.

Heat utilized in evaporation of water.—It is obvious that any water contained in the charge must be evaporated, and the steam thus formed must be raised to the temperature of the stack-gases. It is here that the great difference in economy between the dry and wet methods of mixing is shown.

In the dry method the total water (mechanically held and combined) contained in the charge will rarely rise above 2½ per cent, of which about 2 per cent may be combined in the clay and ½ per cent held mechanically. The products in the dry process, when working with a 60-foot kiln, issue from the stack at a temperature of about 1500° F. =815° C. When a longer kiln is employed, and the trend of present practice seems to be in the direction of 100-foot or even longer cylinders, the stack temperatures will be correspondingly reduced. With a 100-foot kiln it seems probable that they can be kept down at least to 1000° F.

In the wet process, on the other hand, the charge usually contains about 60 per cent of water, though in a few plants this is kept down to 30 or 40 per cent. The stack temperatures are, however, much lower than in the dry process, ranging from about 800° F. with a 60-foot kiln to 450° or so in a 100-foot kiln. This partly counterbalances the loss of heat due to the high percentage of water.

Using these data as a basis, Table 187 has been prepared to show the amount of heat required for simply evaporating the water from three different types of mixture, in kilns of two different lengths.

TABLE 187.

HEAT USED IN EVAPORATION OF WATER.

Process.	Kiln Length, Feet.	Stack Temperature.	Per Cent Water.	Pounds Water per Barrel.	B. T. U. Used per Barrel.
Dry............	60	1500° F.	2½	15	23,367
"	100	1000° F.	2½	15	21,079
Wet............	60	800° F.	30	272	365,650
"	100	450° F.	30	272	336,630
"	60	800° F.	60	900	1,209,870
"	100	450° F.	60	900	1,113,840

Heat utilized in decomposition of clay.—An unknown, though probably small, amount of heat is required to dissociate the clayey portion of the mix. No exact data on this point are known to the writer, but the amount so utilized will probably be covered if we estimate all the water which is really chemically combined with the clay as being *mechanically held water*. This course has been followed in the present estimates. On this assumption, even a dry mix will carry about 2½ per cent of water, and this amount has been accordingly allowed for in the previous paragraph and in Table 187.

Heat utilized in dissociation of sulphates.—A certain amount of heat is taken up in dissociating any lime sulphate (gypsum) present in the raw mix. Newberry has taken this as requiring 1890 B.T.U. per pound of SO_3. In marl plants the percentage of sulphates present may rise to notable quantity, but in most other plants they are negligible. In the present discussion the assumptions will be made that the average dry mix carries 0.3 per cent of sulphur trioxide, and that the usual wet mix may carry 1 per cent. The total amount of heat required for the dissociation of sulphates will therefore be:

Dry mix..........600 lbs. × 0.3% × 1890 = 3,402 B.T.U. per barrel
Wet mix.......... " " × 1.0% × 1890 = 11,340 " " "

Heat utilized in dissociation of carbonates.—The most important heat requirement by far is that for the dissociation of the carbonates of the charge.

The values assumed by Richards for the dissociation requirements of the two carbonates are:

Liberation of 1 kilo CO_2 from $CaCO_3$ = 990 calories.
" " 1 " CO_2 " $MgCO_3$ = 407 "

These are referred to Berthelot. They correspond respectively to the two values of:

Dissociation of 1 pound $CaCO_3$ requires 584 B.T.U.
" " 1 " $MgCO_3$ " 381 "

These values will be accepted in the following calculations for the sake of uniformity, though Ostwald * quotes from Thomsen a value corresponding to 765 B.T.U. for the dissociation of 1 lb. of lime carbonate. If this latter value were accepted, the quantities given in the table below (188) should be reduced about 2½ per cent. Other values for these dissociation constants have been quoted by various authorities, with a much wider range, but for the present purpose those first noted will be satisfactory enough.

Temperature required for clinkering.—Widely differing statements have been made as to the temperature required in order to clinker the average Portland-cement mixture.

Carpenter, in testing the Cayuga plant noted later, determined

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* Lehrbuch der allgemeinen Chemie, vol. II, pt. 1, p. 272.

TABLE 188.

HEAT USED IN DISSOCIATION OF CARBONATES PER BARREL CEMENT.

Percentage MgO in Mixture.	Percentage of Lime (CaO) in Mixture.					
	40%.	41%.	42%.	43%.	44%.	45%.
	B.T.U.	B.T.U.	B.T.U.	B.T.U.	B.T.U.	B.T.U.
0	333,234	342,144	351,054	359,964	368,874	377,784
1%	338,362	347,272	356,182	365,092	374,002	382,912
2%	342,758	351,668	360,578	369,488	378,398	387,308
3%	347,154	356,064	364,974	373,884	382,794	391,704
4%	351,550	360,460	369,370	378,280	387,190	396,100

the kiln temperature by optical methods. The temperature in the kiln when working under best conditions, as determined by the Noel optical pyrometer, varied from 2250° F. near the discharge end to 2950° F. about 20 feet from the lower end, and about 1800° F. at the upper end. The temperature in the burning zone seemed to average about 2850° F., and the temperature of the entire kiln on the inside seemed to average nearly 2500° F.

For ordinary purposes of calculation, it may be assumed that 1400°–1500° C., or 2500°–2700° F., is about the necessary temperature in rotary kilns under present conditions for an average mixture. Variations in the composition of the mixture would, of course, change the clinkering point—for a low-limed high-alumina mix will clinker at a considerably lower temperature than will a mix high in lime and silica.

It is also true that to a certain degree longer exposure to the heat will be equivalent in effects to higher temperature. In stationary kilns, for example, where the charge may be exposed for days to the heat, the requisite temperature is much less than in the modern rapid practice with the rotary kiln.

Heat utilized in heating the mix.—One of the important uses of the kiln heat is in simply heating the mix up to the point at which it will clinker. Fortunately, this can be determined with sufficient accuracy for all practical purposes.

Whatever the percentage of the water present, the dry portion of the mix will be about 600 lbs. for each barrel of cement. This 600 lbs. of material must be raised from the temperature of the air—say 60° F. —to about 1300° F. At this latter temperature the carbon dioxide, sulphur trioxide, etc., will have been driven off; and this will reduce the weight to 380 lbs. This 380 lbs. of quicklime and clay must now be raised to a temperature of about 2600° F., at which clinkering will take place.

Assuming that the above data are substantially correct, and that the specific heat of the mix is about 0.22, the heat required for the simple heating of the mix to the clinkering point can be calculated as follows:

			Per Barrel B.T.U.
600 lbs. mix heated	60° to 1300°, spec. heat	0.22 = 1260 × 0.22 × 600 =	166,320
380 " " "	1300° to 2600°, " "	0.22 = 1300 × 0.22 × 380 =	108,680
Total heat required, B.T.U.			275,000

This estimate is probably above what is actually required, for the temperatures, weights and specific heat have all been taken on the safe side. The actual heat requirements are probably close to 250,000 B.T.U. for this part of the operation.

In running an actual test of a kiln this quantity could be checked roughly by the amount of heat contained in the clinker as it leaves the kiln. In other words, a barrel of clinker carries out with it *almost* as much heat as was required to clinker the raw mix for that barrel.

As pointed out on a previous page (p. 497), the heat required for bringing the mix up to the clinkering point is not utilized in causing chemical changes, and can therefore be utilized again. In this respect it differs from the heat required for dissociating the carbonates and sulphates, decomposing the clay, etc.—for in these cases the heat is absorbed in doing chemical work and cannot be regained. For this reason it will be convenient to omit, from the total thermal requirements, the heat used in heating the mix up to the clinkering point; and to consider it rather in its *outgoing* form as heat carried out by the clinker.

Total heat requirements.—The data given in preceding paragraphs may now be conveniently summed up as in the table below. The basis for the various figures may be seen by referring back to the upper pages.

TABLE 189.

THEORETICAL HEAT REQUIREMENTS IN B.T.U. PER BARREL.

Process	Dry	Dry	Semi-wet	Wet
Length of kiln	60 ft.	100 ft.	60 ft.	100 ft.
Water in mix	2½%	2½%	30%	60%
Stack-gases	1500° F.	1000° F.	800° F.	450° F.
	B.T.U.	B.T.U.	B.T.U.	B.T.U.
Evaporation of water	23,367	21,079	365,650	1,113,840
Dissociation of sulphates	3,402	3,402	11,340	11,340
Dissociation of carbonates	369,488	369,488	369,488	369,488
Total heat required	396,257	393,969	746,478	1,494,668
Coal theoretically necessary, lbs. per bbl.	28	28	53	107
Coal actually used, lbs. per bbl.	120	90	160	150

Heat Losses in Practice.

In practice with the rotary kiln, there are a number of distinct sources of loss of heat, which result in a fuel consumption immensely greater than the theoretical requirements given above. The more important of these sources of loss are the following:

(1) The kiln gases are discharged at a temperature much above that of the atmosphere, ranging from 300° F. to 2000° F., according to the type of materials used and the length of the kiln.

(2) The clinker is discharged at a temperature varying from 200° F. to 2500° F., the range depending as before on materials and length of the kiln.

(3) The air-supply injected into the kiln is always greater, and usually very much greater, than that required for the perfect combustion of the fuel, and the available heating power of the fuel is thereby reduced.

(4) Heat is lost by radiation from the ends and exposed surfaces of the kiln.

(5) The mixture in plants using a wet process carries a high percentage of water, which must be driven off.

It is evident, therefore, that present-day working conditions serve to increase greatly the amount of fuel actually necessary for the production of a barrel of cement above that required by theory.

The extent of these losses, compared with the amount of heat actually used, can be seen from the following comparison of various estimates and tests, all relating to a 60-foot kiln on dry material:

TABLE 190.

UTILIZATION AND LOSSES OF HEAT IN ROTARY KILNS.

	Richards.	Carpenter.	Helbig.	Newberry.	Eckel.	Average.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Total heat supplied to kiln	100.00	100.00	100.00	100.00	100.00	100.00
Heat utilized	19.75	23.43	25.56	25.54	23.59	23.57
Heat lost in clinker	10.72	14.09	12.01	15.47	76.41	13.07
Heat lost in stack-gases	72.46	47.42	50.24	43.62		53.43
Heat lost by radiation	−4.46	15.07	4.88	15.38		7.72
Minor heat losses	1.54	0.00	7.31	0.00		2.21

Heat carried out in flue-dust.—A considerable amount of fine dust is carried out of the kiln by the hot gases. This flue dust, deposited wherever the air current is checked, may amount to from ½ to 3 per cent of the total amount of mix charged to the kiln.

The composition of the flue-dust is a matter of considerable industrial importance. It is composed of the lighter and finer particles of the cement mix and the ash, plus a certain amount of material deposited from the stack-gases. This last factor includes in some cases a large percentage of alkali salts, whose recovery has been suggested as a profitable by-product. (See p. 510.)

Sources of Heat-supply.

To counterbalance the heat utilized and the heat wasted, as above noted, heat is *always* supplied to the kiln from two sources, and occasionally from two other sources. The invariable sources of supply are:

(1) A large and well-known supply is derived from the combustion of the fuel fed to the kiln.

(2) A smaller and very poorly defined supply is obtained from exothermic chemical combinations which take place in the kiln during clinkering.

Supplies from these two sources are necessarily received in every kiln. In addition, however, heat may be supplied from

(3) Regeneration of the clinker heat.

(4) Utilization of the heat in the stack-gases.

Heat supplied by combustion of fuel.—The most important source of the heat supplied to the kiln is, of course, the burning of the fuel injected into it. This can be estimated accurately enough, for any given kiln, if the composition of the coal and the amount of coal used per barrel of cement are known. It must be borne in mind, however, that any defects in the coal-feeding arrangements, or deficiencies in the fineness of coal grinding, should not properly be charged against the efficiency of the kiln, but against the efficiency of the superintendent. In calculating the heat supplied to the kiln by combustion of fuel the assumption is always made that the coal is ground as fine as is economically possible, and that the injecting apparatus gives perfect combustion. Actually we know that neither of these assumptions is ever quite justified and that in some mills both are very incorrect.

If the best bituminous coal from western Pennsylvania or West Virginia be used, a theoretical heating value of 14,000 B.T.U. per lb. may be assumed: but the coals used in practice often fall very far short of this. Such a coal, used at the rate of 120 lbs. per barrel of cement, would give a heat supply of 1,680,000 B.T.U. per barrel. This is probably about equal to the *average* practice with 60-foot kilns on a dry mixture of limestone and clay. With longer kilns, under specially favorable circumstances, a fuel consumption of 90 lbs. per barrel may be expected, corresponding to a heat supply of 1,260,000 B.T.U. per barrel. With the wet process a fuel consumption of 160 lbs. per barrel is rather better than the average. This corresponds to a heat supply of 2,240,000 B.T.U. per barrel. These three estimates have therefore be used in making up the summary table.

Heat supplied by chemical combinations.—It is undoubtedly true that a considerable quantity of heat must be liberated when the lime and magnesia combine, at the clinkering temperature, with the silica, alumina and iron oxide, and that in this way considerable heat is added to that derived from the fuel. Unfortunately, however, we have no very definite knowledge as to the exact chemical combinations which take place during clinkering, and lacking such knowledge any estimate of the amount of heat thus liberated must be considered as merely a wild guess.

Both Helbig and Richards, in the papers previously cited, have quoted Berthelot on this point as giving the following data for the heat liberated during this combination.

1 kilogram lime (CaO) liberates	530 calories
1 " magnesia (MgO) liberates	827 "

These figures, changed into English measures, are:

1 pound lime (CaO) liberates	954 B.T.U.
1 " magnesia (MgO) liberates	1489 "

For convenience these figures might be adopted in discussion, but both the reader and experimenter must bear in mind that they represent very doubtful assumptions, and are accepted merely because no better data are obtainable. In the present discussion of the subject no estimate of this type will be used.

Heat derived from the clinker.—A large part of the heat carried out in the hot clinker may be used to heat the incoming air. In Carpenter's experiments a little less than half of the clinker heat was thus utilized, but other experimenters have claimed 80 to 90 per cent efficiency for various types of clinker-heat regenerators. The amount of heat thus returned to the kiln might therefore vary from 90,000 to 175,000 B.T.U. per barrel of cement.

Heat derived from the stack-gases.—Heat may also be taken from the stack-gases and used to heat either the raw material or the air-supply. Usually, however, stack-gas heat when utilized is used in the power department of the mill, rather than in the kiln.

Estimates and Tests of Heat Distribution.

Various estimates of the heat requirements of cement-manufacture have been presented by different authors, and several actual tests have been made of heat distribution in the rotary kiln. The principles on which these calculations are based have been discussed in the preceding pages, and the estimates and tests in question will now be presented for comparison.

Newberry's estimates.—Some years ago Prof. Newberry published a discussion of the question of fuel consumption which leaves little to be desired even in spite of recent changes in rotary practice. His results are summarized in Table 191.

TABLE 191.

NEWBERRY'S ESTIMATES ON HEAT DISTRIBUTION IN KILNS.

	Vertical Kiln.		Rotary Dry Process.		Rotary Wet Process.	
	B.T.U.	Per Cent.	B.T.U.	Per Cent.	B.T.U.	Per Cent.
Evaporation of water.	14,498	3.7	20,832	3.3	827,424	59.3
Liberation of sulphates.	11,340	2.8	11,340	1.8	11,310	0.8
Dissociation of carbonates. .	344,250	88.9	344,250	54.7	344,250	24.6
Heating of mix and clinker	. . . .	. . . .	228,000	36.3	213,312	15.3
Heating of CO_2 and SO_3 from mix.	16,646	4.6	24,480	3.9		
Total B.T.U. required. . . .	386,734	100.0	628,902	100.0	1,396,326	100.0
Lbs. coal required per bbl., theoret. air-s'ply	31.0	. . . .	66.9	. . . .	120.0	
Lbs. coal required per bbl., 50% excess air. .	32.1	. . . .	82.2	. . . .	128.7	
Lbs. coal actually used in practice.	42–46	. . . .	110–120	. . . .	150–160	

Helbig's estimates.—Very recently Mr. A. B. Helbig has discussed this question, but only incidentally to a subject of more importance, i.e., the utilization of waste heat. Mr. Helbig's figures, slightly rearranged for convenience of comparison, will be found in Table 193 on page 509.

Results of actual tests.—It might be supposed that actual tests of the thermal efficiency of the rotary kiln could be readily made, and that the results of these tests would afford data of great value to the manufacturer. To a certain extent this is true, but, unfortunately, the results afforded by such tests require interpretation, and this in turn requires that certain chemical constants—so called by courtesy—should be employed as bases. These constants are, for example, the heat of dissociation of the carbonates and the sulphates, of the decomposition of clay, of the formation of lime silicates and aluminates, etc. The error into which most experimenters fall is to assume that these constants are quite accurately known. As a matter of fact, even the simplest of them—the heat of dissociation of lime carbonate—is given a variation of almost 50 per cent by different chemists of about equal standing; while the heats of formation of the silicates, etc., are much less certain constants.

In reporting and discussing actual tests, or in reading the reports of such tests, it must, therefore, be borne in mind that the assumptions which are necessarily made are based, in large part, on determinations of more than questionable accuracy.

Two such tests have been recently published, by Richards and Carpenter respectively, and are summarized below.

Richards' tests.—Prof. J. W. Richards tested a 60-foot rotary at the Dexter Portland Cement Company plant, Nazareth, Pa. The cement mixture and the resulting clinker are said to have had the following compositions:

	Raw Mix.	Clinker.
Silica (SiO_2)	13.38	21.27
Alumina (Al_2O_3)	6.04	6.42
Iron oxide (Fe_2O_3)		3.18
Lime (CaO)	41.96	66.70
Magnesia (MgO)	1.53	2.43
Carbon dioxide (CO_2)	34.65	
Water	0.43	

The clinker "analysis" must evidently have been calculated from the raw mix, and not obtained by direct analysis.

A proximate analysis of the kiln coal—bituminous stack from Fairmount, W. Va.—gave:

Volatile matter	38.10
Fixed carbon	53.24
Ash	8.06
Moisture	0.60

"The following ultimate composition of the coal was assumed from average analyses of coal from that region of similar proximate composition.

Carbon	73.60
Hydrogen	5.30
Nitrogen	1.70
Sulphur	0.75
Oxygen	10.00
Moisture	0.60
Ash	8.05

"The kiln turns out an average of 3635 lbs. of clinkered cement per hour from 5980 lbs. of material fed to it, producing 200 lbs. of flue-dust, equal to 3.35 per cent of the weight of mixture charged. The coal used averages 110 lbs. per barrel of cement produced."

The temperature of the clinker falling out of the lower end of the kiln was measured by the Le Chatelier pyrometer, and determined to be 1200° C.=2192° F. The temperature of the waste gases, determined 4 feet below the top of the stack, was 820° C. or 1508° F. The sensible heat in the clinker (leaving the kiln at 1200° C.) was determined by a calorimeter as 290 kilogram calories per kilo=522 B.T.U. per pound. The waste gases in the stack analyzed as follows:

Carbon dioxide	10.2
Oxygen	11.8
Carbon monoxide	0.2
Sulphur dioxide	not determined
Water	"
Nitrogen	"

It will be noted that part of these preliminary data were determined by direct experiment, while others apparently are "averages," or otherwise of less value than experimental results. This, unfortunately, throws doubt upon some of the results obtained, as noted below. At the close of his paper, after making the necessary calculations, Mr. Richards summarized his results. This summary, recalculated to calories and B.T.U. per barrel, is presented below.

TABLE 192.

SUMMARY OF RICHARDS' TESTS OF ROTARY KILNS.

	Heat-units per Barrel.		
	Calories.	B.T.U.	Per Cent.
HEAT SUPPLY.			
Theoretical heating power of the fuel	395,000	1,567,460	84.7
Heat of combination of the clinkering materials	71,410	283,355	15.3
	466,410	1,850,815	100.0
HEAT DISTRIBUTION.			
Heat carried out by hot clinker	50,025	198,499	10.7
Heat in waste gases in necessary products	170,000	674,560	36.1
Heat in waste gases in excess air, etc.	168,000	666,625	36.0
Heat in the flue-dust	1,056	4,190	0.2
Loss by imperfect combustion	6,124	24,300	1.3
Evaporation of water of charge	723	2,869	0.2
Dissociation of the carbonates	10,814	42,910	2.3
Loss by radiation, etc. (by difference)	59,668	236,862	12.8
	466,410	1,850,815	100.0

In regard to Richards' results it may be said that the use of such a large excess of air is not normal practice, either in the Lehigh district in general or at the Dexter plant in particular. It is further doubtful whether a kiln run so wastefully as this one appears to have been could make good cement with a fuel consumption as low as 110 lbs per barrel. These questions throw doubt on the calculated loss of heat in the waste gases. The amount allowed for dissociation of the carbonates is apparently only about one-tenth of what should be allowed, owing to an arithmetical error. When this error is corrected, the "loss of heat by radiation" is made a minus quantity. In Table 193 below, this correction has been made, but Richards' estimates as to waste gases are left unchanged.

Carpenter's tests.—Prof. R. C. Carpenter tested two rotary kilns at the plant of the Cayuga Portland Cement Company, near Ithaca, N. Y. The test was made primarily to determine the efficiency, not of the kilns, but of a boiler designed to utilize their waste heat.

The coal used in the kilns was Westmoreland (Pa.) slack of the following composition and heating value.

Moisture	2.19
Volatile matter	32.9
Fixed carbon	54.66
Ash	10.25
B.T.U. per pound	14,022

At the time of test the two kilns were taking together 1889 lbs. coal per hour, producing 21.2 barrels of clinker, equal to a coal consumption of 89.1 lbs. per barrel. This low fuel consumption is attained in part by the use of waste heat from the clinker as shown in the table below.

Carpenter's paper, as originally published, contained a number of serious typographic errors, which the author has kindly corrected on the copy sent to me. In the table below I have therefore made use of these corrected results, so that the second column of this table (193) will be found to differ considerably from that given in the original.

It will be seen that Richards' results, when corrected for the carbonate requirements, leave no room for radiation losses.

For my own detailed estimates on most of these points, the reader is referred back to pages 498, 501.

TABLE 193.

TESTS AND ESTIMATES OF HEAT DISTRIUBTION, B.T.U. PER BBL.

	Richards.	Carpenter.	Helbig.	Newberry.
Heat from combustion of coal.	1,567,460	1,247,641	992,000	1,474,000
" drawn from clinker cooler . . .	. . . .	96,273	149,348	
" derived from chemical combination.	283,355	132,456	240,770	?
Total heat supplied.	1,850,815	1,476,370	1,382,118	1,474,000
Heat used in evaporation of water. .	2,869	14,302	3,214	20,832
" " " dissociation of sulphates.	. . . .	11,233	4,500	11,340
" " " dissociation of carbonates.	362,524	320,253	345,625	344,250
Heat discharged in clinker *.	198,499	207,999	165,942	228,000
" " " stack-gases, necessary products.	674,560	700,093	694,400	462,940
Heat discharged in stack-gases, excess air.	666,625			180,000
Heat discharged as CO (imperfect combustion)	24,300			
Heat discharged in flue dust.	4,190	. . . .	14,134	
" " by radiation, etc. .	. . . .	222,490†	67,456‡	226,638§
Total heat distributed.	1,933,567	1,476,370	1,295,271	1,474,000

* Roughly equivalent to the heat necessary to bring the mix up to the clinkering point.
† By difference.
‡ By calculation.
§ Does not check, owing in part to temperature allowances.

Heat Utilization and Economics.

Much of the heat carried out by the clinker and the stack-gases is recoverable with some ease, while that lost by radiation from the kiln is not so readily utilized. Helbig and Carpenter have described methods of waste-heat utilization in the papers cited on p. 511, to which reference should be made for further details.

Carpenter, in discussing his Cayuga tests, notes that "at the time of the test that portion of the air not supplied by the coal-feeding apparatus was forced by a special blower through the hot clinker and thence into the kiln. By this regenerative action about 80 per cent of the entering air was heated to 480° F., restoring to the *two* kilns about 2,000,000 B. T. U. per hour, or about 7 per cent of the heat produced by the combustion of the coal. The regenerator, while distinctly economical, made the clinker elevators difficult to keep in order and tended to deliver dust into the kiln-room; it also took up valuable room and after a few months of use was abandoned. The test shows, however, the value of conserving the waste heat from the clinker by heating the entering air." As the clinker of the two kilns during this test carried out 4,409,540 B.T.U. per hour, and the clinker regenerator returned 2,041,000 of this, its efficiency was 46.3 per cent.

At a German Portland-cement plant where the stack-gases are used in drying the raw materials, a large amount of very fine dust settles from the stack-gases in the drying chamber. This dust has been examined † by Seger and Kramer, and found to consist of 43.65 per cent of insoluble and 56.35 per cent of soluble matter. The insoluble matter gave: silica 31.4 per cent, alumina 14.7 per cent, iron oxide 4.9 per cent, lime 36.8 per cent, magnesia 1.3 per cent, loss on ignition 0.9 per cent. The soluble portion consisted of potassium sulphate 61.1 per cent, and potassium carbonate 38.9 per cent. Calculating these proportions to percentages of the total dust, we have:

Silica (SiO_2)	13.71
Alumina (Al_2O_3)	6.42
Iron oxide (Fe_2O_3)	2.14
Lime (CaO)	16.06
Magnesia (MgO)	0.57
Potash carbonate	34.43
Potash sulphate	21.92
Loss on ignition	4.76

The composition of this stack-dust has directed attention to the possibility of utilizing it as a source of potash, and both American and foreign patents have been taken out to cover possible processes for this purpose.

List of references on heat requirements.—The following list contains the principal papers dealing with this phase of cement-manufacture. Those marked with an asterisk are restricted mainly to a discussion of clinkering temperatures, etc.

* Bleininger, A. V. Manufacture of hydraulic cements. Bulletin No. 3, Ohio Geological Survey, 1904.

* Campbell, E. D. Some preliminary experiments upon the clinkering of Portland cement. Journ. Amer. Chemical Soc., vol. 24, pp. 969–992, Oct., 1902.

* Campbell, E. D., and Ball, S. An experiment upon the influence of the fineness of grinding upon the clinkering of Portland cement. Journ. Amer. Chem. Soc., vol. 25, pp. 1103–1112, Nov., 1903.

* Campbell, E. D. Further experiments on the clinkering of Portland cement and on the temperature of formation of some of the constituents. Journ. Amer. Chem. Soc., vol. 26, pp. 1143–1158, Sept., 1904.

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† Journ. Soc. Chem. Industry, vol. 23, p. 661. June 30, 1904.

Carpenter, R. C. A test of a process for utilizing waste heat from rotary cement-kilns. Sibley Journal of Engineering, March, 1904.

Helbig, A. B. The efficiency of waste-gas boilers in connection with rotary cement-kilns. Engineering News, vol. 53, pp. 163–166, Feb. 16, 1905.

Newberry, S. B. Fuel consumption in Portland-cement burning. Cement and Engineering News, July, 1901.

Richards, J. W. The thermal efficiency of a rotary cement-kiln. Cement, vol. 5, pp. 30–35, 1904.

CHAPTER XXXV.

REQUISITES AND TREATMENT OF KILN FUELS.

The usual fuel in rotary-kiln practice is pulverized bituminous coal. Oil, natural gas, and producer gas are, however, used at several plants, while charcoal has recently been suggested for use in a projected Arizona mill. These fuels will be discussed in the order named.

Coal.

Character of kiln coals.—In order to be suitable for use in rotary kilns the coal must be of the bituminous type, and preferably a gas-coal. Coals high in fixed carbon and low in volatile matter, while giving high temperatures, will not burn properly when pulverized and blown into the kiln, for they are slow to ignite. The anthracite and semi-bituminous coals are, therefore, ruled out, though they can be used in small quantities mixed with gas-coal, if the mixture be pulverized fine enough.

For economic reasons the kiln coal should run as low in ash as possible. The ash not only lowers the heating value of the coal, but it interferes with the composition of the mix, for much of it is always taken up by the cement during burning. The presence of sulphur, in amounts of over 1½ per cent, is also technologically a defect, and if the sulphur averages over 2 per cent it is advisable to look up a better coal.

As shown by the analyses below, the better coals actually used range in composition about as follows:

Volatile matter	30%–40%
Fixed carbon	50%–60%
Sulphur	0%– 1½%
Ash	5%– 8%

Analyses of kiln coals.—The following table (194) of analyses of kiln coals is fairly representative of the various types of coal actually in use in rotary-kiln plants.

TABLE 194.

ANALYSES OF KILN COALS.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Volatile matter	32.90	38.10	31.38	35.41	35.26	39.52	39.37	31.87	37.44	38.00
Fixed carbon	54.66	53.24	58.23	56.15	56.33	51.69	55.82	51.05	53.72	51.72
Sulphur	n. d.	n. d.	n. d.	1.30	1.34	1.46	0.42	n. d.	n. d.	n. d.
Ash	10.25	8.06	9.42	6.36	7.06	6.13	3.81	5.22	5.50	5.38
Moisture	2.19	0.60	1.03	2.08	1.35	1.40	1.00	11.86	3.334	4.90

1. Westmoreland,, Pa., slack, used at Cayuga Cement Co., Portland Point, N. Y. R. C. Carpenter. Cement, vol. 5, p. 1904.
2. Fairmount, W. Va., slack, used at Dexter Portland Cement Co., Nazareth, Pa. J. W. Richards. Cement, vol. 5, p. 30.
3. Fairmount, W. Va., slack, used at Alpha Portland Cement Co., Alpha, N. J. F. E. Walker, analyst.
4. West Virginia slack, used by Wolverine Portland Cement Co. at Coldwater, Mich. H. E. Brown, analyst. 22d Ann. Rep. U. S. Geol. Sur., pt. 3, p. 675.
5. West Virginia slack, used by Wolverine Portland Cement Co. at Quincy, Mich. H. E. Brown, analyst. 22d Ann. Rep. U. S. Geol. Sur., pt. 3, p. 675.
6. West Virginia slack, used by Peninsular Portland Cement Co., Cement City, Mich. J. G. Dean, analyst. 22d Ann. Rep. U. S. Geol. Sur., pt. 3, p. 675.
7. Pennsylvania slack, used by Omega Portland Cement Co., Jonesville, Mich. 22d Ann. Rep. U. S. Geol. Sur., pt. 3, p. 675.
8. Ohio coal, used by Wellston Portland Cement Co., Wellston, Ohio. W. S. Trueblood, analyst.

9, 10. Ohio coal, used by Ironton Portland Cement Co., Ironton, Ohio. C. D. Quick, analyst.

References on coal-fields.—The following reports contain data on the distribution and character of American coals.

Ashley, G. H. The coal deposits of Indiana. 23d Rep. Indiana Dept. Geology and Natural Resources, pp. 1–1573. 1899.

Ashley, G. H. The eastern interior coal-field (Illinois and Indiana). 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 265–306. 1902.

Bain, H. F. The western interior coal-field (Iowa, Missouri, Kansas). 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 333–366. 1902.

Diller, J. S. The Coos Bay coal-field, Oregon. 19th Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 309–376. 1898.

Haseltine, R. M. The bituminous coal-field of Ohio. 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 215–226. 1902.

Hayes, C. W. The coal-fields of the United States (summary). 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 7–24. 1902.

Hayes, C. W. The southern Appalachian coal-field (Ala., Ga., Tenn., Ky., Va.). 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 227–264. 1902.

Lane, A. C. The northern interior coal-field (Michigan). 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 307–332. 1902.

Smith, G. O. The Pacific Coast coal-fields (Oregon, Washington, California). 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 473–514. 1902.

Storrs, L. S. The Rocky Mountain coal-fields (Mont., Wyo., Colo., Utah, N. Mex.). 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 415–472. 1902.

Taff, J. A. The southwestern coal-field (Ind. Terr., Ark., Texas). 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 367–414. 1902.

White, D. The bituminous coal-field of Maryland. 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 201–214. 1902.

White, D., and Campbell, M. R. The bituminous coal-field of Pennsylvania. 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 127–200. 1902.

White, J. C. Report on coal (of West Virginia). Vol. 2, Reports W. Va. Geol. Survey, pp. 81–725. 1903.

Woodworth, J. B. The Atlantic Coast Triassic coal-fields (Virginia, North Carolina). 22d Ann. Rep. U. S. Geol. Survey, pt. 3, pp. 25–54. 1902.

Crushing.—Coal may be bought in the shape of slack, lump or run-of-mine. In the former case no preliminary crushing is required, for the slack can be readily handled by ball mills, Griffin mills, or Williams mills. When slack is bought, therefore, it is sent direct to the drier and then to the fine-reducing mills. But when lump or run-of-mine are purchased the coal can profitably be crushed before being sent to the drier.

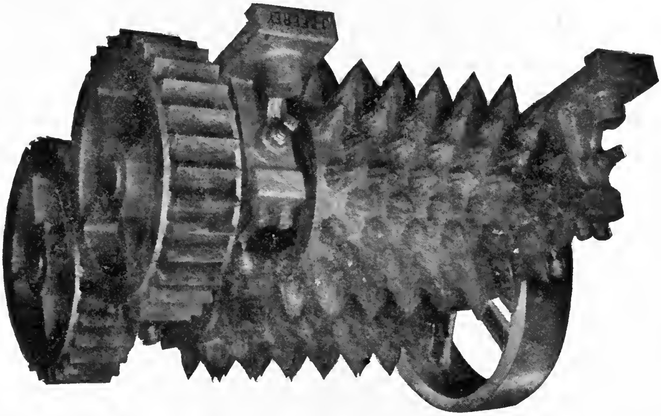

FIG. 127.—Coarse, toothed rolls for lump coal. (Allis-Chalmers Co.)

In such cases the preliminary crushing seems to be accomplished most effectually by rolls. Figs. 127 and 128 show rolls adapted to this kind of work, both being made by the Allis-Chalmers Co. The rolls shown in Fig. 127 are very coarsely toothed, and are intended for use on large lump or run-of-mine coal. They are 24″×30″ in size, and can conveniently reduce large lump to about 1- or 2-inch size. In Fig, 128 a set of 24″×18″ plain-faced disintegrating rolls are shown. These will handle coal up to say, 4 to 6 inch size, and reduce it economically to $\frac{3}{8}$ or $\frac{1}{2}$ inch. Finer than this it is hardly profitable to go, for $\frac{1}{2}$-inch coal is readily dried and is of convenient size for either ball, Griffin, or Williams mills.

Drying coal.—Coal, as bought, may carry as high as 15 per cent of water in winter or wet seasons; usually, it will run from 3 to 8 per cent. To secure good results from the crushing machinery it is necessary that this water should be driven off. For coal drying, as for the drying of raw materials, the rotary drier seems best adapted to American conditions. Several types of these driers are discussed on pp. 400 and 649. It should be said, however, that in drying coal it is inadvisable to allow the products of combustion to pass *through* the cylinder in which the coal is being dried. This restriction serves to decrease slightly the possible economy of the drier, but an evaporation of 6 to 8 pounds of water per pound of fuel coal can still be counted on with any good drier. The fuel cost of drying coal containing 8 per cent of moisture, allowing $2 per ton for the coal used as fuel, will therefore be about 3 to 4 cents per ton of dried product.

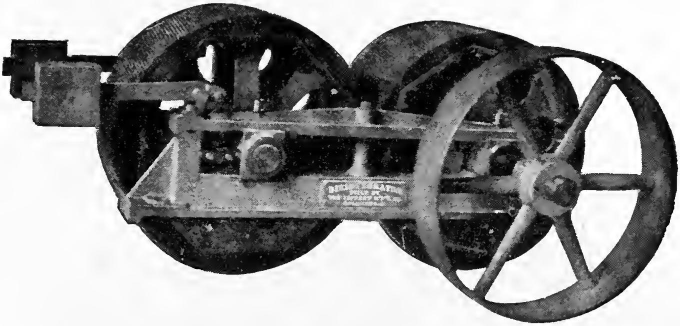

FIG. 128.—Rolls for coal-crushing. (Allis-Chalmers Co.)

Pulverizing coal.—Though apparently brittle enough when in large lumps, coal is a difficult material to pulverize finely. For cement-kiln use, the fineness of reduction is very variable. The finer the coal is pulverized the better results will be obtained from it in the kiln, and the poorer the quality of the coal the finer it is necessary to pulverize it. The fineness attained in practice may, therefore, vary from 85 per cent through a 100-mesh sieve to 95 per cent or more through the same. At one plant a very poor but cheap coal is pulverized to pass 98 per cent through a 100-mesh sieve, and in consequence gives very good results in the kiln.

Coal-pulverizing is usually carried on in two stages, the material being first crushed to 20- or 30-mesh in a Williams mill or ball mill and finally reduced in a tube mill. At many plants, however, the entire reduction takes place in one stage, Griffin or Huntingdon mills being used.

Descriptions of the Williams, Griffin, and Huntingdon mills, and of several makes of ball mills and tube mills, will be found in Chapter XXXV. The Smidth ball mill, however, was not described in that chapter, and as it is recommended by its manufacturers for use as an intermediate reducer on coal, its general make-up can properly be noted here.

The following description of the Smidth ball mill is given by its makers:

"The illustration (Fig. 129) shows the internal arrangement of the type A ball mill. This machine has a through-shaft, with journals running in bearings at both ends.

"The machine consists of a drum with two strong end-plates *c*, between which the curved drum-plates *d* are fixed. As will be seen these drum-plates do not form a cylinder, but one end of each is set a few inches toward the center, forming steps. The balls and materials tumble over these steps when the drum revolves, and by this the pounding action of the balls is considerably increased, the steps at the same time allowing the residue from the sieve to be caught and re-enter the drum. The curved drum-plates are protected on the inside by thick steel plates *e* which are divided in several sections, so that each section can be separately renewed. The lining plates are fixed by means of bolts. The end-plates *c* are also lined with thick plates *cl*.

"The grinding-plates have rows of perforations *f* through which the crushed material constantly falls on the slotted-steel screen-plates *g*. Whatever is fine enough to pass these screen-plates falls on the inner sieves *l*, which are coarse and strong sieves, and that which passes through these falls on the finishing-sieves *k*. The material passing the finishing-sieves is collected in the lower hopper-shaped part of the dust-casing *m* surrounding the drum, and from this it either falls to a conveyor or elevator, or may be dropped direct into the containers. The outlet of the dust-casing is provided with a slide-gate.

"The residue from the sieves, coarse and fine, is carried up with the mill until it falls through large holes in the curved part *f* of the slotted-steel screen-plates, and, together with the residue from the slotted-steel screen-plates themselves, falls into the drum again through the steps.

"In one of the end-plates a manhole is fitted and in the dust-casing a door corresponding to the manhole, giving access to the interior

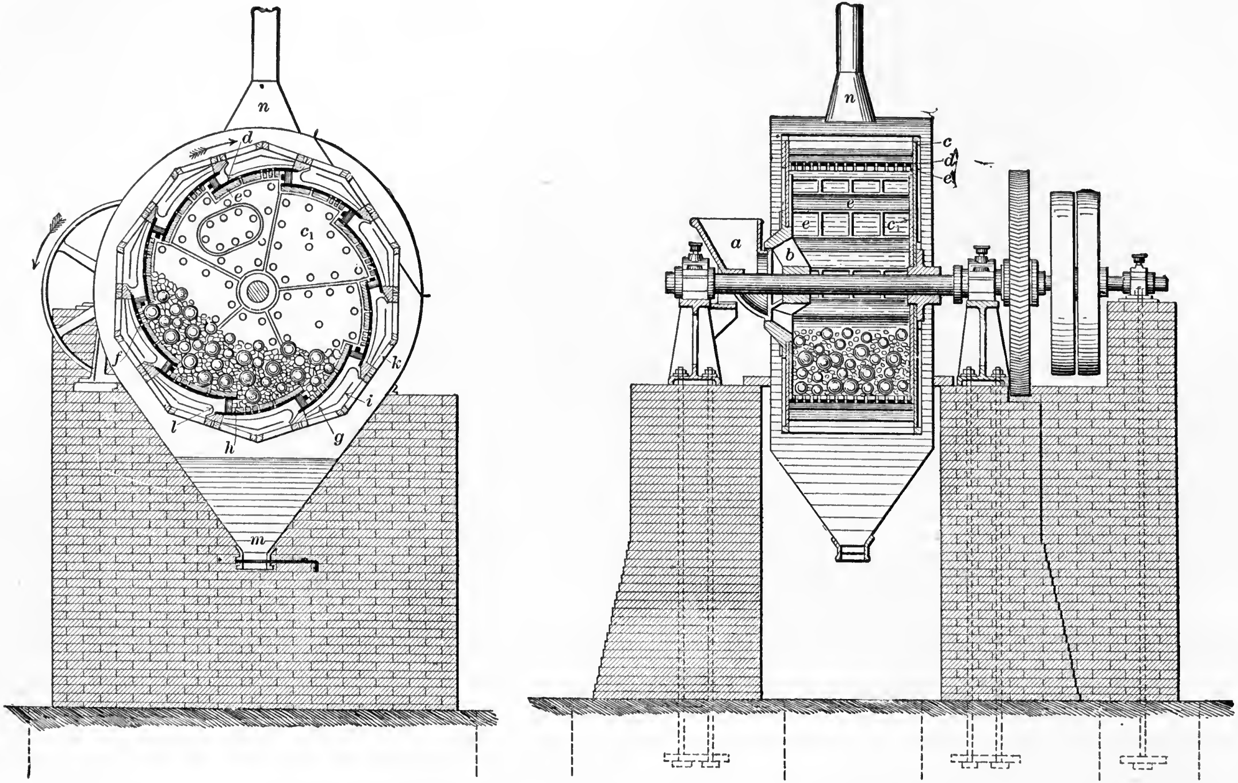

Fig. 129.—Sections of Smidth ball mill, type A. (F. L. Smidth & Co.)

of the mill. The dust-casing is made in three parts, a small section being easily removable for brushing the sieves. The top half may be removed for repair of the drum.

"The illustration below (Fig. 130) shows the type B machine, which is the same as type A, except that the shaft, instead of going through the feed-hopper, is stopped short inside the drum and there fixed in a 'spider' the external part of which runs on a roller bearing. By means of this arrangement lumps up to 10 inches each way can be fed into the mill, and the feed opening itself at the same time is reduced in diameter, which allows a heavier charge of balls to be used.

"The very large capacity of the Davidsen tube mill as a pulverizer created the demand for a large ball mill of sufficient capacity to feed the tube mill with coarse material. This demand has been met by the type C ball mill, in the construction of which the through-shaft of type A and the 'spider' of type B have been omitted, giving a clear feeding opening of 10 inches without interference. The omission of the shaft and the 'spider' have made it possible to use a much larger charge of steel balls and at the same time lower the cost of repairs by avoiding the necessity for replacement of either shaft or 'spider'.

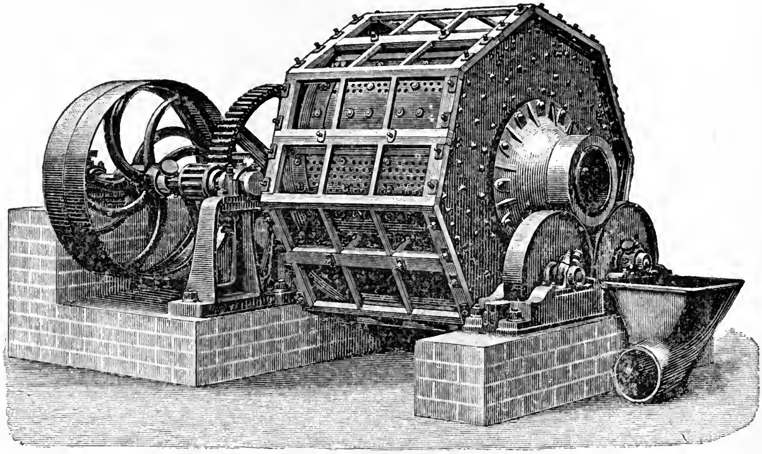

Fig. 130.—Smidth ball mill. (F. L. Smidth & Co.) Type B, showing roller bearing as used on type C.

" Up to this time there has been but one size of the type C constructed, namely, No. 7. This has become the popular form and size for Portland-cement work. One No. 7 ball mill and one No. 12 tube mill can be brought together as a grinding unit through placing on the ball-mill screen-frames wire cloth of such mesh as shall be shown by the grindability of the material to pass the proper capacity for pulverization in the tube mill. No. 7 ball mill requires at the maximum 18 horse-power and uses a floor space of 11 feet 4 inches by 15 feet 7 inches. Like the tube mill, the ball mill is a slow-speed machine, making 22 revolutions per minute.

"The parts most subjected to wear are the grinding-plates, the side linings, the gear, and the pinion. Depending entirely upon the character of the material, the grinding-plates should give a wear of from six to eighteen months. The side linings do not wear so rapidly. As the gear and pinion are operated at slow speed the wear on these is relatively small. Gears are seldom replaced short of one or two years and pinions have a life of from six to twelve months. Of course gears and pinions wear in proportion to the attention given to lubrication and protection from dust."

Power and output in coal-grinding.—There is probably greater diversity in coal-grinding practice than in the grinding of either raw material or clinker. Grinding-machines of many different types are in use; the coal reaches the plant in various sizes from slack to lump, and is ground to different finenesses. All this makes it difficult to estimate closely on the power requirements and output of the coal-grinding mill, but the following data may be of use in this connection.

A Williams mill employed at an Illinois cement-plant, working on Illinois coal from the dryer and preparing it for the tube mills, ground six tons of coal per hour to the following fineness.

Mesh of sieve	20	50	100	200
Per cent residue	6.9	43.3	76.2	87.3
Per cent passing	93.1	56.7	23.8	12.7

If the results of this test be compared with those given on p. — for the same mill working on raw materials, it will be seen that coal is very readily crushed to 20-mesh, and quite easily to 50-mesh. But the percentages of coal passing the 100-mesh and 200-mesh sieves respectively are very much lower than the percentages of raw mix passing the same sieves.

A Griffin mill grinding coal from rolls or small crushers will reduce about two tons per hour to a fineness of 95 per cent through a 100-mesh screen, taking 25 to 30 H.P. in doing so.

Slack coal for three kilns is ground at one plant in a single No. 16 Davidsen tube mill, the product being about three tons per hour.

The above data show a considerable variation in the power required for coal-grinding, the performances quoted being equivalent to power consumptions of from 5 to 15 H.P. hours per ton of coal ground. Mr. C. D. Bartlett, in discussing * this question, states that a good mill will handle slack at the rate of four tons per hour, crushing it to 80-mesh and using about 25 H.P. in doing so. For kiln use, of course, the fineness must be considerably greater than this.

Total cost of coal preparation.—The total cost of crushing (if necessary), drying, and pulverizing coal, and of conveying and feeding the product to the kiln, together with fair allowances for replacements and repairs, and for interest on the plant, will probably range from about 20 to 30 cents per ton of dried coal for a four-kiln plant. This will be equivalent to a cost of from 3 to 5 cents per barrel of cement. While this may seem a heavy addition to the cost of cement-manufacture, it should be remembered that careful drying and fine pulverizing enable the manufacturer to use much poorer, and therefore cheaper, grades of coal than could otherwise be utilized.

The coal used at American plants costs from 80 cents to $2.50 per ton delivered at the mill, according to the quality of the coal and the location of the mill. In the West, where good coal is far more expensive than stated, oil is used in its place.

It is probably safe to say that if a plant is so located that coal will cost over $4 per ton, and no oil or gas is obtainable, the rotary kiln is too expensive for use. Under such fuel conditions it is probably best to install stationary kilns of one of the improved designs described in Chapter XXXII. This is particularly the case if a wet mix be used in the kilns.

Fire and explosion risks.—The coal-handling end of the plant is subject to two quite distinct, though related, kinds of risks—from explosion and fire respectively. Precautions must be taken to guard against both of these dangers.

Explosions may occur when finely divided powdered coal is given free access to air. In order to keep as little powdered coal on hand as possible, the coal-mill is usually run so as to just supply the kilns. This has some inconveniences, but it lessens the risk. During grinding care must be taken to prevent the use of exposed lights or even motors, which are apt to spark, in the coal-pulverizing building. The methods of supplying coal to the kiln should give as little access to air as possible. Separation by blowing is, of course, inadmissible, as was emphasized by the fatal results at the Edison plant in 1903.

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* Journ. Assoc. Engineering Societies, vol. 31, pp. 44–48. 1903.

In addition to the risk of explosion from coal-dust, there is always the chance that coal stored in bulk will heat up and cause a disastrous fire.

The following statement regarding coal storage has been recently published * by F. M. Griswold, General Inspector to the Home Insurance Company, of New York:

"The quantity stored in any one pile, heap, pocket, or bunker should in no case exceed 1,500 tons. When a greater quantity must be stored there should be a clear space of at least 5 feet between the piles, and that space should be maintained absolutely free for ventilation and dispersion of gases from the mass.

"No accumulation of coal of 1500 tons or less should be piled in excess of 12 feet in height, when trimmed off, or squared, but where such accumulation is delivered from dump-cars on a trestle over 12 feet in height, the extreme height of the pile formed by the natural run of the coal as dumped may be 15 feet, but not more.

"Where coal is stored under shelter, there should be perfect ventilation, to facilitate escape of gas by circulation of the atmosphere.

"Wet coal, especially that wetted by snow and ice, should be disposed for immediate use; if its storage be necessary, it should be placed at the top of the pile and be spread out as thinly as practicable, in order to expedite drying.

"All accumulations of coal, large or small, should be 'rod-tested' with frequency and regularity, in order to discover any tendency toward dangerous heating, the danger-point being set at about 160° F. If that temperature be reached, the exact locality of increasing heat may be determined by inserting an iron pipe, into which a self-registering thermometer can be lowered, allowing it to remain for sufficient time to record the full intensity of the heating."

List of references on coal drying, grinding, etc.

Bartlett, C. D. The burning of pulverized coal. Journ. Assoc. Engineering Societies, vol. 31, pp. 44–48. 1903.

Doane, A. O. The spontaneous ignition of coal. Engineering News, vol. 52, p. 141. Aug. 18, 1904.

Frazier, W. H. Fire hazards in Portland-cement mills. New York Journal of Commerce, April, 1901.

Griswold, F. M. Specifications for storage of bituminous coal. Engineering and Mining Journal, vol. 77, p. 725. 1904. Engineering News, vol. 52, pp. 409–410. Nov. 10, 1904.

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* Engineering and Mining Journal, vol. 77, p. 725. 1904.

Lathbury, B. B., and Spackman, H. S. The Lathbury and Spackman coal-drier. The Rotary Kiln, pp. 150–151. 1902.

Anon. Powdered fuel for boiler-furnaces at the Alpha Cement Co.'s works, Alpha, N. J. Engineering News, 1897.

Anon. A new system for burning powdered coal. Engineering News, vol. 48, p. 548. Dec. 25, 1902.

Oil.

Petroleum was early used in New York and Pennsylvania as a fuel for rotary kilns, but was gradually supplanted by powdered coal. At present no Eastern plants use oil as fuel. In the West, however, where good gas coals are unobtainable at reasonable prices, oil is now in use at four Portland-cement plants.

From 11 to 14 gallons of oil are required in Western practice to burn a barrel of cement; a safe estimate is that one barrel of oil (42 gallons) will burn three barrels of cement. Oil may, therefore, be compared with coal, in the rotary kiln, on the basis of 1 gallon of oil being equal in effect to 10 lbs. of coal.

List of references on petroleum.—The papers on petroleum contained in the following list are of interest either as containing discussions of the fuel value of petroleum, or as describing certain oil fields whose product is at present utilized in Portland-cement manufacture.

Eldridge, G. H. The Florence oil field, Colorado. Trans. Amer. Inst. Mining Engrs., vol. 20, pp. 442–462. 1892.

Eldridge, G. H. The petroleum fields of California. Bulletin 213, U. S. Geological Survey, pp. 306–321. 1903.

Fenneman, N. M. The Boulder, Colorado, oil field. Bulletin 213, U. S. Geological Survey, pp. 322–332. 1903.

Peckham, S. F. Petroleum in southern California. Science, vol. 23, pp. 74–75. 1894.

Anon. Fuel oil on the Pacific Coast. Engineering and Mining Journal, Dec. 20, 1902.

Natural Gas.

Use of natural gas in kilns.—Natural gas is at present used as a kiln fuel in several Kansas plants and at one in Ohio. As a kiln fuel it is satisfactory enough, giving as much results per B.T.U. as does a good coal. Apparently, however, a gas-fired kiln cannot be pushed as hard as a kiln using coal, though the data are insufficient to give any decisive evidence on this point. A recent report on a Western cement proposition states that the natural gas to be used in the kilns has been contracted for at the rate of 3 cents per thousand feet. This is about equivalent to coal at 90 cents per ton.

Analyses and thermal value.—The following analyses, made * by Prof. E. H. S. Bailey, will serve to give some idea of the composition of natural gas from a number of Kansas localities.

TABLE 195.

ANALYSES OF NATURAL GAS, KANSAS.

	Iola.	Independence.	Cherryvale.	Coffeyville.	Paola.	Ossawatomie.
Hydrogen (H)	0.00	0.00	0.00	0.00	0.00	0.00
Oxygen (O)	0.45	trace	0.22	0.12	0.45	trace
Nitrogen (N)	7.76	3.28	5.94	2.21	2.34	0.60
Carbon monoxide (CO)	1.23	0.33	1.16	0.91	1.57	1.33
Carbon dioxide (CO_2)	0.90	0.44	0.22	0.00	0.33	0.22
Ethylene series (C_2H_4, etc.)	0.00	0.67	0.00	0.35	0.11	0.22
Marsh-gas (CH_4)	89.66	95.28	92.46	96.41	95.20	97.63

TABLE 196.

THERMAL VALUES OF NATURAL GAS.

State.	Field.	B.T.U. per Cubic Foot.	State.	Field.	B.T.U. per Cubic Foot.
Indiana	Anderson	1021	Pennsylvania.	East Liberty	592
"	Kokomo	1030	"	Grapeville	823
"	Marion	1024	"	"	891
"	Muncie	1019	"	Harvey	990
Kentucky	Louisville	939	"	Leechburg	1073
New York	Olean	1071	"	St. Joe	1170
" "	West Bloomfield	998	West Virginia	Fairmount	1137
Ohio	Findlay	1100	" "	Lumberport	1131
"	"	1020	" "	Morgantown	1143
"	Fostoria	1016	" "	Shinnston	1141
"	St. Mary's	1028	" "	"	1144
Pennsylvania.	Cherry Tree	840	" "	"	1065
"	Creighton	1025			

List of references on natural gas.—Of the following papers, those marked with an asterisk are of interest as discussions of the fuel value of natural gas, while those unmarked contain data on its utilization in the Iola district.

Adams, G. I., and others. Economic geology of the Iola quadrangle, Kansas. Bulletin 238, U. S. Geological Survey, 83 pp. 1904.

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* "Mineral Resources of Kansas for 1897", p. 52.

Crane, W. R. Natural gas in steam production (in Kansas). Mines and Minerals, vol. 24, pp. 154–156. Nov., 1903.

Grimsley, G. P. A new Portland-cement mill in the gas-fields of Kansas. Engineering and Mining Journal, Feb. 16, 1901.

Bailey, E. H. S. Natural gas and coal oil in Kansas. Kansas University Quarterly, vol. 4, pp. 1–14. 1895.

* Bownocker, J. A. Occurrence and exploitation of petroleum and natural gas in Ohio. Bulletin 1, 4th Series, Ohio Geol. Survey, 1903, p. 125.

* Ford, S. A. Fuel value of Pittsburg gas. American Manufacturer, supplement, April, 1886.

* Howard, C. D. Composition and fuel value of West Virginia gas. Vol. I*a*, Reports West Virginia Geol. Survey, pp. 553–556. 1904.

* Orton, E. Preliminary Report upon Petroleum and Natural Gas (in Ohio). 1887, pp. 53–54.

* Phillips, F. C. The chemical composition of natural gas. Report I, 2d Geol. Survey Penna., pp. 787–827. 1887.

* Phillips, F. C. The chemical composition of natural gas. Vol. I*a*, Reports West Virginia Geological Survey, 1904, pp. 513–552.

* White, I. C. The composition of natural gas. Vol. I*a*, Reports West Virginia Geological Survey, 1904, pp. 513–557.

Producer-gas.

Producer-gas has been used in rotary kilns at three American plants at least. Two of these plants report that their best fuel consumption, when producer-gas was used, was equivalent to 220 to 240 lbs. coal per barrel of cement. The third plant, however, has recently experimented with the Swindell gas-producer, and reports that a really economical fuel consumption is attained.

Producer-gas from wood or lignite.—A cement-plant located in a district where wood, lignite, or poor coal were the only natural fuels would probably get good results by utilizing these fuels in the gas-producer. A recent installation of this type at a Mexican copper-plant has utilized wood, bituminous coal, and anthracite.

This plant, in respect to the use of wood, is described † as follows:

"The plant has been operated with wood and with coal, both anthracite and bituminous. The down-draught principle of the producers, by which all gases pass out through the bottom of the fire, has proved thoroughly efficacious in producing fixed gases from all kinds of fuel used at Nacozari. The water from the scrubber rarely shows even that trace of tar which manifests itself by an iridescent film on the surface of the water in the lower scrubber tank.

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† Langton, J. The power-plant of the Moctezuma Copper Co., Mexico. Trans. Amer Inst. Mining Engineers, Oct., 1903.

"The use of producer-gas made from wood alone is the most novel feature of the plant. No guiding experience was found for this process; but, with the desire to utilize as far as possible the limited local wood-supply, the gas-producer plant was selected with the object, among other things, of determining the advisability of using, if not wood alone, at least a considerable admixture of wood with bituminous coal. The most obivous difficulty to be feared arose from the large proportion of condensible distillates yielded by wood, and the danger that some portion of these might be imperfectly fixed in passing through the producer. The trouble from tar deposited in the gas apparatus and pipes would be serious, and even a small quantity of tar in the gas itself is a fertile source of trouble at the engine-valves. Unless a permanent gas could be made from wood, this fuel would be unavailable.

"The first care, therefore, was to insure that there should be a bed of charcoal on the grate sufficient to form an adequate fixing-zone. To obtain this the producers were filled about 5 feet deep with cordwood sawn in blocks about 6 inches long and the contents blown with a slow fire for four or five hours before the gas was turned into the holder. The gas, as it proved, was turned into the holder too soon. At first it contained some tar, and it was not until after three hours' operation that the charcoal accumulated in sufficient quantity, so that the producers delivered fixed permanent gases to the holder.

"The character of the gas produced from different fuels is shown by the following averages from a series of analyses made by A. Sandberg, of Lund, during the final trials of the gas-making plant, which extended from February 16 to March 20, 1901.

Average Composition of Gas from Different Fuels.

Fuel.	Components.				
	CO.	H.	CH_4.	CuH_2N.	CO_2.
Anthracite coal	21.6	12.68	1.86	0.18	8.1
Bituminous coal	20.32	13.08	2.35	0.2	7.66
Wood	13.27	20.97	2.61	0.28	15.96

Fuel.	Components.		Calorific Value. B.T.U. per Cubic Foot at 60° F. and 29.9 Inches Barometric Pressure.
	O.	N.	
Anthracite coal	0.2	55.38	131.1
Bituminous coal	0.04	55.35	133.27
Wood	0.11	46.80	140.22

"As compared with coal-gas, the proportions of CO and H in wood-gas are reversed, and the percentage of CO_2 is doubled. With the typical compositions (see page 525) the wood-gas shows less tendency than the coal-gas to pre-ignition in the engines. This effect appears to be due to the large proportion of CO_2, but the reason why this is so is not apparent."

Charcoal.

The use of charcoal as a rotary kiln fuel has been seriously suggested recently by at least one engineer for a plant located where no other type of fuel was obtainable at reasonable rates. It is, however, a matter of serious doubt whether this material could be brought to ignite properly before it reached the stack.

CHAPTER XXXVI.

CLINKER COOLING, GRINDING, AND STORAGE. USE OF GYPSUM.

The clinker, issuing hot from the rotary kilns, must be very finely ground in order to convert it into cement. This involves cooling the clinker previous to grinding; otherwise the hot clinker would be difficult to handle both in transportation and in the pulverizing machinery. A third requisite of the process is that either the clinker or the ground cement must be seasoned, in some way, in order to slake any free lime that may be present. Modern clinker invariably contains some free lime, and while its effects may be masked by the free use of gypsum, it is advisable to give it as much opportunity as possible to slake and become inert.

In the present chapter, therefore, the subjects of clinker-cooling, clinker-grinding, the use of gypsum and cement storage will be taken up.

Clinker-cooling.

General methods of clinker-cooling.—Methods of clinker-cooling vary exceedingly in their processes and effectiveness. At one extreme might be placed the device, used at one plant only, of receiving the clinker from each kiln in a shute which passes through the wall of the kiln building and deposits the clinker in a heap on the ground outside. This is, of course, a remarkably simple process, mechanically, but as it involves hand-labor to an alarming extent it is hardly probable that any other American plants will take it up. At the other extreme is, decidedly, the Atlas two-stage cooling system.

Omitting the crude device first mentioned above, clinker-cooling systems may be roughly grouped as follows:

(1) Pan conveyors, rolls, and sprinkling.
(2) Stationary tower coolers.
(3) One-stage rotary coolers.
(4) Two-stage (Atlas) rotary coolers.

These methods will be briefly discussed in the order named.

Pan conveyors, rolls, and sprinkling.—At a number of plants the hot clinker is caught, as it drops out of the kiln, in pan conveyors. As it passes along in these it is sprinkled with fine jets of water, and at some point of its progress is passed through a pair of rolls. This method therefore contains all the elements of any cooling system, and in a very simple form. It is not adapted to utilize the heat of the clinker however, and the product even after sprinkling and passing the rolls is too hot to be sent immediately to the grinding-mills. The simplicity of the method is therefore counterbalanced by a loss of heat and relatively high amount of hand-labor.

Stationary tower coolers.—Many plants use stationary coolers in the form of towers. The Mosser cooler, shown in section in Fig. 131, is a good example of this type. The cooling installation at the Buckhorn plant is described as follows by Mr. Humphreys in Engineering News:*

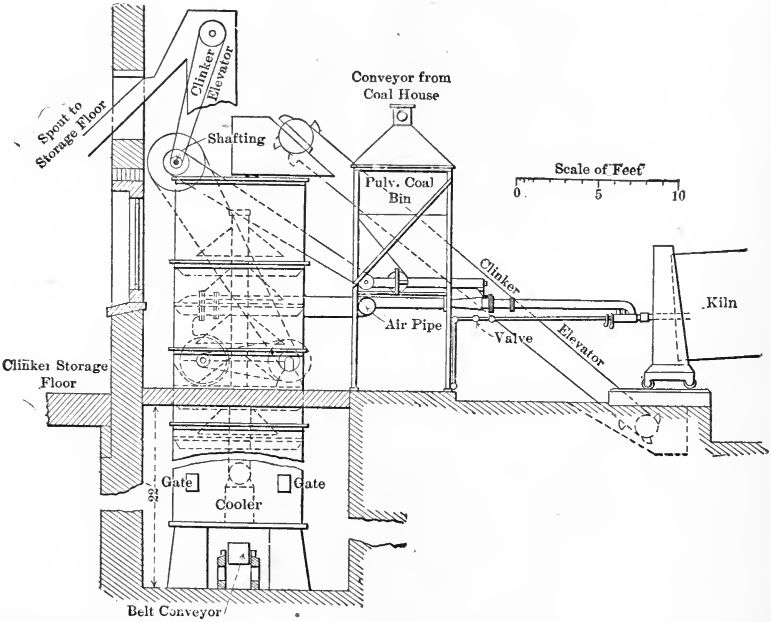

FIG. 131.—Tower cooler, Buckhorn Portland Cement Co. (Engineering News.)

"Each pair of kilns discharges through a fire-brick-lined shute into the boot of a single-chain open elevator.

"As the clinker falls into the buckets of this elevator it is sprayed

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* Humphreys, R. L. The plant of the Buckhorn Portland Cement Co. Engineering News, vol. 50, pp. 408–411. Nov. 5, 1903.

with water. The elevator dumps the clinker into a cooler built by Wm. F. Mosser & Son. There are three of these coolers, each 32 feet high, 8 feet in diameter, having a cast-iron blast-pipe running through the center, with sheet-steel conical shields every 5 feet, extending to within 10 inches of the shell of the cooler.

"Under this shield are holes in the blast-pipe, through which a constant flow of fresh air is maintained by means of a fan, the air passing out of the cooler through holes in its shell the latter having conical shields on the inside just above these openings.

"The heat of the clinker is absorbed in the vaporization of the water and is removed by the current of air which passes through the thin stream of clinker moving through the cooler between the two shields.

"The coolers rest on a cast-iron plate, supported by foundations 4 feet high, in a pit about 20 feet below the kiln-room floor. Running under these coolers are belt conveyors which receive the cooled clinker (drawn from four openings in each cooler) and carry it to the boot of an elevator, which discharges it through an opening in the wall between the kiln room and the clinker ball-mill department onto a storage floor."

One-stage rotary cooler.—The next step in clinker-cooling devices is the use of rotary coolers. These are simply rotary driers, reversed in action, and require no special description here.

Atlas two-stage rotary cooler.—By far the most satisfactory of cooling devices is the two-stage rotary cooler employed by the Atlas Portland Cement Company. It is, so far as the writer knows, the only cooling system which really cools the clinker to a handling temperature and does so quickly and economically.

The cooling system at the main Atlas plant was described by Stanger and Blount in 1901 as follows:

"The clinker drops from the burning cylinder into a second rotating cylinder, about 30 feet long and 3 feet in diameter, revolving about six times as fast as the burning cylinder. This is lined with fire-brick, and through it passes a current of air which goes to feed the flame of burning coal-dust. The greater part of the sensible heat in the clinker is thus saved and utilized. The clinker, still moderately hot, falls on to three crushing rolls contained in a housing and moistened by a spray of water. As shown in the figure a pair of kilns with their accompanying first cooling cylinders converge so as to deliver the clinker onto these rolls and from this point a single secondary cooling apparatus serves this pair of kilns. The object of the rolls is to crush large lumps of clinker which may have been formed by the aggregation of a number of small fragments adhering together when plastic in the burning cylinder. These lumps being built up of small pieces loosely stuck together differ entirely from the tough hard masses formed in a fixed kiln fed with blocks or bricks of raw material, and are readily broken up to the size of a hazelnut. The warm moist clinker passes down a third rotating cylinder 60 feet long by 5 feet in diameter, lined with hard cast-iron plates provided with shelves so as to toss and tumble the pieces as they creep down. Air is drawn in through this cylinder by means of a chimney which also carries off the water vapor from the housing of the rolls. It is intended that the clinker shall emerge from the end of the last cooling cylinder, in a slightly moist condition, and to ensure this, regulation of the water at the rolls is supplemented by a small jet at the end of the last cooler."

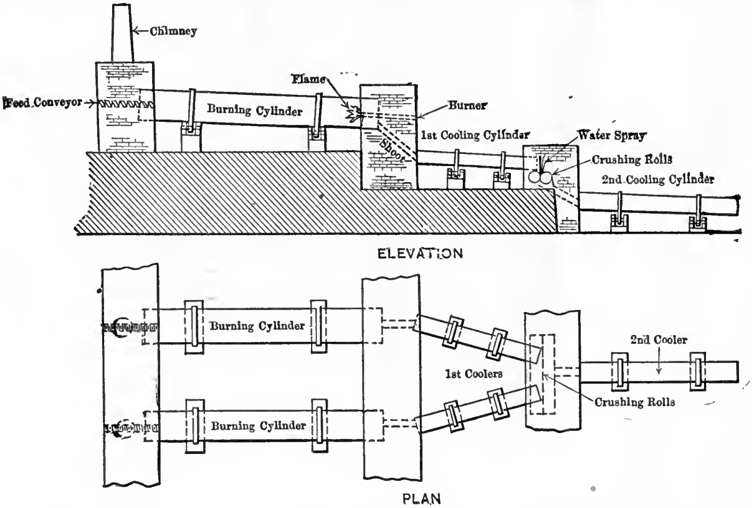

Fig. 132.—Atlas rotary two-stage coolers. (Engineering News.)

This system is shown in Fig. 132, taken from the paper * below cited.

Clinker-grinding.

After cooling sufficiently to be workable, the clinker passes to the clinker-grinding department of the mill. The problem before this department is to reduce large quantities of an intensely hard and semi-vitrified material to finely ground cement at the lowest cost possible. This reduction is now usually accomplished in two or three stages.

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* Stanger, W. H., and Blount, B. The rotary process of cement-manufacture. Proc. Inst. Civil Engineers, vol. 145, pp. 57–68. 1901. See especially p. 62 for coolers.

Somewhere in the process it is necessary to provide for the addition of a certain comparatively small percentage of gypsum or plaster, in order to bring the setting properties of the cement up to commercial requirements. Though this addition is commonly made *during* the grinding process, it will be discussed later in the chapter.

The power allowed and machinery installed for pulverizing the clinker at a Portland-cement plant using the dry process of manufacture are very closely the same as that required for pulverizing the raw materials for the same output. This may seem, at first sight, improbable, for Portland-cement clinker is much harder to grind than any possible combination of raw materials; but it must be remembered that for every barrel of cement produced about 600 lbs. of raw materials must be pulverized, while only a scant 400 lbs. of clinker will be treated, that the large crushers required for some raw materials can be dispensed with in crushing clinker, and that the raw side rarely runs full time. The raw material side and the clinker side of a dry-process Portland-cement plant are, therefore, usually almost or exactly duplicates.

The difficulty, and in consequence the expense, of grinding clinker will depend in large part on the chemical composition of the clinker and on the temperature at which it has been burned. The difficulty of grinding, for example, increases with the percentage of lime carried by the clinker, because of the higher burning which has been necessary, and a clinker containing 64 per cent of lime will be very noticeably more resistant to pulverizing than one carrying 62 per cent of lime. So far as regards burning, it may be said in general that the more thoroughly burned the clinker the more difficult it will be to grind, assuming that its chemical composition remains the same.

The tendency among engineers at present is to demand more finely ground cement. While this demand is doubtless justified by the results of comparative tests of finely and coarsely ground cements, it must be borne in mind that any increase in fineness of grinding means a decrease in the product per hour of the grinding-mills employed, and a consequent increase in the cost of cement. At some point in the process, therefore, the gain in strength due to fineness of grinding will be counterbalanced by the increased cost of manufacturing the more finely ground product.

The increase in the required fineness has been gradual but steady during recent years. Most specifications now require at least 90 per cent to pass a 100-mesh sieve; a number require 92 per cent; while a few important specifications require 95 per cent. Within a few years it is probable that almost all specifications will go as high as this.

The following description of the clinker-grinding side of the plant of the Hudson Portland Cement Co. has recently appeared in Engineering News. The layout of this plant is shown in Fig. 85, p. 407:

"The kilns are 60 feet long and 6 feet in diameter, and each is driven by a 7½-H.P. electric motor. Fig. 4 is a view of the under side of the kilns showing the rolls on which they run. The immense size of these modern cement burners is excellently indicated by this illustration. From the kilns the clinker is run into rotary coolers. There are five of these, one for each pair of kilns. In these coolers the clinker is cooled by a current of air which is blown in at the forward ends and passes out of the rear ends into the trunk mains whence the air-pipes to the kilns branch off. The coal is thus blown into the kilns by heated air. From each cooler the clinker drops into a clinker pit and from these pits the elevators *G* hoist it to the bins of the five Krupp ball mills.

"From the ball mills the underground screw conveyor 14 and the elevator *H* take the powder to the double hopper where the final adjustment of proportions is made if necessary, and thence the conveyor 15, the elevator *HH*, and the conveyor 16 take the powder to the feed-bins of the seven tube mills, for final grinding. The discharge from the tube mills is taken by the conveyor 16½ to conveyor 26, which leads to the storage-bins.

"The course of the coal through the drier and grinders in the coal-grinding room and thence by conveyor 24, elevator *L*, and conveyor 26 to the powdered coal-bins for the kilns can be readily traced from the drawings, and need not be explained further here."

Actual practice. — The following data relate to the machinery actually used on the clinker-grinding side of a number of American plants and will serve to give a good idea of present practice in that line:

Plant No. 1. Dry process: 3 kilns, about 450 barrels per day.
1 small jaw-crusher;
2 ball mills;
2 tube mills.

Plant No. 2. Dry process: 4 kilns, about 700 bbls. per day.
1 rotary cooler;
2 Smidth ball mills to 8 mesh;
1 Bonnot ball mill to 30 mesh;
4 tube mills.

- *Plant No. 3.* Wet process: 3 kilns, about 240 bbls. per day.
  - 1 crusher;
  - 1 set rolls;
  - 7 run millstones;
  - 2 tube mills.
- *Plant No. 4.* Wet process: 13 kilns, about 1300 bbls. per day.
  - 4 ball mills;
  - 4 tube mills.
- *Plant No. 5.* Wet process: 3 kilns, about 350 bbls. per day.
  - 3 Smidth ball mills, No. 7;
  - 3 Davidsen tube mills, No. 12.
- *Plant No. 6.* Dry process: 6 kilns, about 1200 bbls. per day.
  - 1 set rolls;
  - 5 Bonnot ball mills;
  - 5 Bonnot tube mills.
- *Plant No. 7.* Wet process: 5 kilns, about 550 bbls. per day.
  - 1 rotary cooler;
  - 2 Smidth ball mills, No. 7;
  - 2 tube mills.
- *Plant No. 8.* Wet process: 14 kilns, about 1200 bbls. per day.
  - 1 set rolls;
  - 15 Griffin mills.
- *Plant No. 9.* Wet process: 6 kilns, about 600 bbls. per day.
  - 3 ball mills;
  - 3 tube mills.
- *Plant No. 10.* Wet process: 14 kilns, about 1600 bbls. per day.
  - 2 rotary coolers;
  - 6 ball mills;
  - 6 tube mills.
- *Plant No. 11.* Wet process: 10 kilns, about 1100 bbls. per day.
  - 4 ball mills;
  - 4 tube mills.
- *Plant No. 12.* Wet process: 9 kilns, about 1300 bbls. per day.
  - 1 roll-crusher;
  - 10 Griffin mills;
  - 3 Griffin mills.
- *Plant No. 13.* Dry process: 3 kilns, about 525 bbls. per day.
  - 1 crusher;
  - 2 ball mills;
  - 2 tube mills.

Plant No. 14. Dry process: 10 kilns, about 1600 bbls. per day.
7 ball mills;
7 tube mills.

Plant No. 15. Dry process: 8 kilns, about 1300 bbls. per day.
4 ball mills;
6 tube mills.

Plant No. 16. Dry process: 6 kilns, about 1000 bbls. per day.
4 ball mills;
4 tube mills.

Plant No. 17. Dry process: 6 kilns, about 1200 bbls. per day.
1 kominuter and 3 ball mills;
4 tube mills.

Plant No. 18. Wet process: 21 kilns, about 3000 bbls. per day.
32 Griffin mills.

Plant No. 19. Dry process: 10 kilns, about 1700 bbls. per day.
5 rotary coolers;
5 ball mills;
6 tube mills.

Plant No. 20. Wet process: 10 kilns, about 1400 bbls. per day.
1 cracker;
2 kominuters;
5 tube mills.

Plant No. 21. Dry process: 3 kilns, about 450 bbls. per day.
1 Williams mill;
2 tube mills.

Plant No. 22. Dry process: 4 kilns, about 700 bbls. per day.
1 cracker;
7 Griffin mills.

Plant No. 23. Dry process: 2 kilns, about 300 bbls. per day.
2 ball mills;
2 tube mills.

Use and Effects of Gypsum or Plaster.

The high-limed clinker now produced in the rotary process is naturally very quick-setting. In order to retard its set sufficiently to pass commercial requirements, sulphate of lime, in the form of gypsum or plaster, is now universally employed. This substance, when added in quantities up to 2 to 3 per cent, retards the set of the cement proportionately, and also increases somewhat its tensile strength in short time tests. In larger quantities, its retarding influence becomes less, and finally negative, while a decided weakening of the cement is noticeable.

The more theoretical part of the discussion, relating to the form in which the sulphate is applied, and the influence of various percentages of sulphate on the set and strength of the cement, will be first presented: after which the actual methods of application, with analyses of gypsums and plasters used in practice, will be discussed.

Form in which calcium sulphate is used.—The requisite calcium sulphate may be added to the cement in one of three forms: as crude gypsum, as calcined plaster, or as dead-burnt (anhydrous) plaster. For a full description of the manufacture and properties of these three products the reader is referred to Part I of this volume. In the present place their essential characters can be briefly stated as follows: Crude gypsum is a natural hydrous sulphate of lime, corresponding to the formula $CaSO_4+2H_2O$, and to the composition calcium sulphate 79.1 per cent, water 20.9 per cent. Calcined plaster, or plaster of Paris, is obtained by heating gypsum at temperatures of 350°–400° F., the result being that three fourths of the combined water is driven off. The resulting plaster has the formula $CaSO_4+\frac{1}{2}H_2O$, corresponding to the composition calcium sulphate 93.8 per cent, water 6.2 per cent. If gypsum be calcined at temperatures much above 400° F., all of its combined water will be expelled, leaving dead-burnt or anhydrous plaster, which is simply $CaSO_4$.

Considerable discussion has been aroused over the question, which of these three forms of calcium sulphate is the more advantageous for use: but few satisfactory series of experiments are on record in regard to this point. A misleading statement often made is that plaster of Paris, because of its greater chemical activity, will naturally be much more effective than gypsum, weight for weight. The fallacy involved in this statement is revealed when it is considered that the calcium sulphate added to the cement has absolutely no effect until the mixture is gauged with water; and that this addition of water will naturally reconvert the plaster immediately into the hydrous lime sulphate, gypsum. Any argument based on relative chemical activity, so-called, is therefore fallacious.

The results of a few recorded experiments, on the comparative effects of the various forms of calcium sulphate, on the set and strength of the cement, will be given below: after which the conclusions which may be drawn from these experiments and from commercial conditions and actual practice will be summarized.

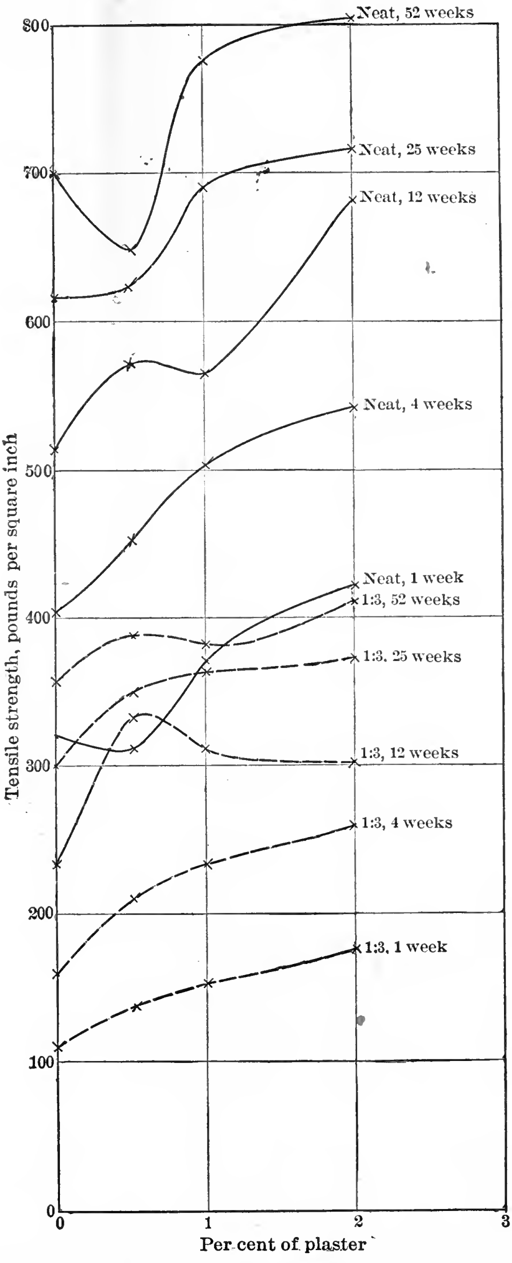

FIG. 133.—Effect of plaster on strength; different ages and compositions. (Dyckerhoff.)

Nihoul and Dufossez, in the course of the experiments described on page 540, tested the comparative effect of calcium sulphate in four different forms—i.e., as crude gypsum, as calcined plaster, as anhydrous plaster and as chemically precipitated calcium sulphate. Their conclusions were: (1) that with the precipitated calcium sulphate and calcined plaster the retardation of set is proportional to the amount of sulphate added: and, (2) that with crude gypsum this is true only when less than 2 per cent of gypsum is employed, larger percentages causing acceleration rather than retardation of set.

Lewis has carried out a short series of experiments on the influence of calcium sulphate on the strength of the cement, applying the calcium sulphate in three different forms—gypsum, plaster of Paris, and anhydrous plaster. The results, given in the table below, are not decisive: but seem to show a somewhat greater regularity of effect when plaster of Paris or anhydrous plaster are used than when gypsum is employed.

TABLE 197.

EFFECT OF FORM OF SULPHATE USED. (LEWIS.)

Amount Added.	Tensile Strength, 7 Days Neat.			Tensile Strength, 7 Days, 3:1.		
	Anhydrous Sulphate.	Plaster of Paris.	Crude Gypsum.	Anhydrous Sulphate.	Plaster of Paris.	Crude Gypsum.
0 per cent......	444	444	444	196	196	196
1½ " "	....	589	....	....	212	
2 " "	647	651	673	....	215	
3 " "	....	729	541	....	225	179
4 " "	663	524	533	148	165	194
5 " "	293	247	593	127	66	179
6 " "	....	254	....	....	63	

To summarize the matter: The active retarding agent is the sulphur trioxide present in the gypsum or plaster. As anhydrous plaster and plaster of Paris both contain somewhat higher percentages of SO_3 than gypsum, they will exercise a proportionally greater retarding effect, weight for weight, than will gypsum. But for ordinary practice this slight advantage is immensely counterbalanced by the fact that gypsum costs usually less than half as much as either of the plasters: and for ordinary practice, therefore, gypsum is the only form of calcium sulphate that can be considered available. In certain plants, however, where the sulphate is added *after* the cement has been ground, it is necessary to use plaster of Paris; because gypsum as bought is ground too coarsely to add to a finely pulverized cement.

Effect of calcium sulphate on set of cement.—Experiments on the effect of setting time of the addition of gypsum or plaster are fairly numerous. Unfortunately, such records mean very little, unless they are accompanied by sufficient data, as to the chemical composition, fineness, etc., of the cement; to enable some idea to be formed concerning the general type of cement tested. Experiments on low-limed cement can not be fairly compared with those carried out on high-limed cements; and cement made in stationary kilns behaves differently from the usual product of the rotary.

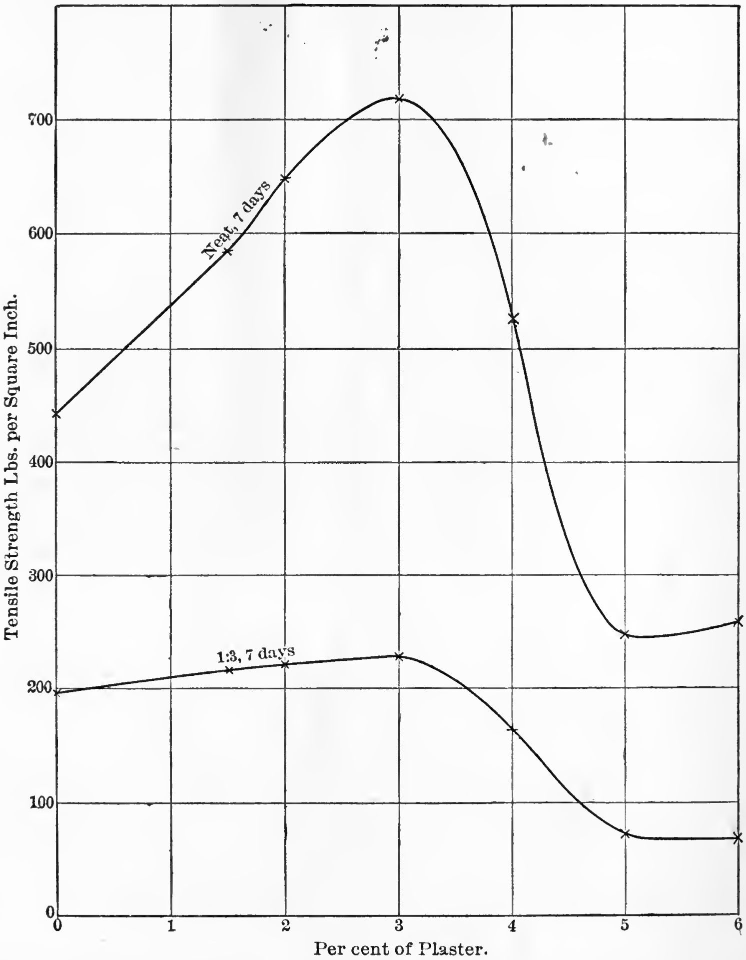

FIG. 134.—Effect of plaster on tensile strength of Portland cement. (Lewis.)

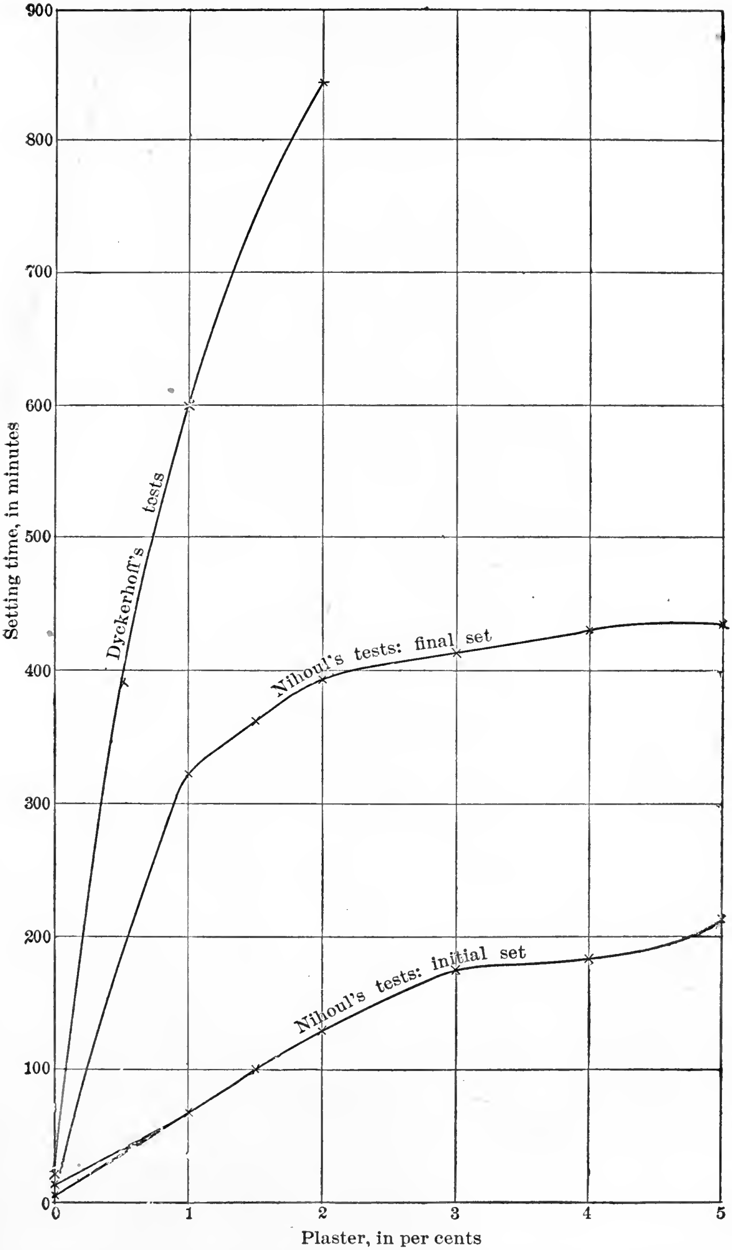

FIG. 135.—Effect of plaster on setting-time of Portland cement. (Dyckerhoff's tests; Nihoul's tests.)

In the experiments * of Nihoul and Dufossez a commercial Portland cement of the following composition was used:

Silica (SiO_2)	22.80
Alumina (Al_2O_3)	7.79
Iron oxide (Fe_2O_3)	1.27
Lime (CaO)	65.80
Magnesia (MgO)	0.59
Carbon dioxide (CO_2)	1.36
Water	0.20

It is to be noted that this cement, though probably made in a stationary kiln, is very high-limed and correspondingly quick-setting. It can therefore be considered as closely similar to the average rotary clinker.

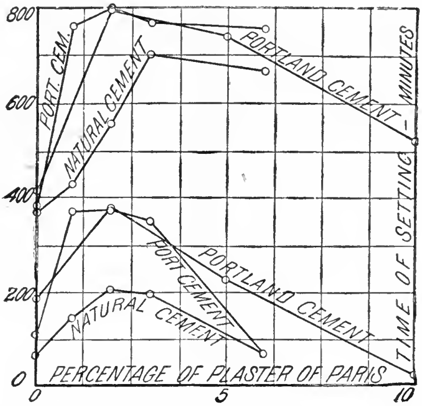

FIG. 136.†—Effect of plaster on setting-time. (Sabin.)

TABLE 198.

EFFECT OF ADDING VARIOUS PERCENTAGES OF CALCINED PLASTER.

(NIHOUL AND DUFOSSEZ.)

Composition.	Initial Set.		Final Set.	
	Hours.	Minutes.	Hours.	Minutes.
Pure cement	0	8	0	13
Cement with 1 per cent plaster	1	10	5	20
“ “ 1½ “ “ “	1	40	6	0
“ “ 2 “ “ “	2	7	6	32
“ “ 3 “ “ “	2	51	6	50
“ “ 4 “ “ “	3	0	7	10
“ “ 5 “ “ “	3	33	7	12

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* Journ. Soc. Chem. Industry, vol. 21, pp. 859–860. 1902.

† From Johnson's "Materials of Construction", p. 187.

TABLE 199.

EFFECT OF CALCINED SULPHATE ON SET OF CEMENT. (DYCKERHOFF.)

Per Cent Plaster Added.	Setting-time, Hours.	Minutes.
0	0	20
1½	3	30
1	10	0
2	14	0

Results obtained by Dyckerhoff * are given in the table above. It is unfortunate that no analysis of the cement experimented on is obtainable, in view of the remarkably great retardation effected by very small percentages of sulphate.

A very unusual set of results, obtained in experiments, by Messrs. Kniskern and Gass, has recently been published † by Prof. R. C. Carpenter. Clinker was procured from a cement-plant in unground form and ground in the laboratory, being mixed with various percentages of gypsum. The results are as follows:

TABLE 200.

EFFECT OF GYPSUM ON SETTING-TIME. (KNISKERN AND GASS.)

Per Cent Gypsum.	Initial Set, Minutes.	Final Set, Minutes.	Per Cent Gypsum.	Initial Set, Minutes.	Final Set, Minutes.
0	2	52	4	28	45
½	6	87	4½	22	40
1½	80	157	5	27	59
2	24	114	5½	20	78
2½	29	79	6	19	37
3	30	69	6½	22	40
3½	27	72	7	18	59

These results are shown diagrammatically in Fig. 137 and comparison of this curve with those of Figs. 135 and 136 will show their unique character. The maximum effect was obtained with 1½ per cent of gypsum, and a rapid decrease in effect was shown when 2 per cent or more was used. Unfortunately no analysis is given of the cement experimented on, so that we cannot judge whether or not there is any reason for these curious results.

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* Proc. Inst. Civ. Engrs., vol. 62, p. 156. 1880.

† Engineering News, vol. 53, pp. 13–14. Jan. 5, 1905.

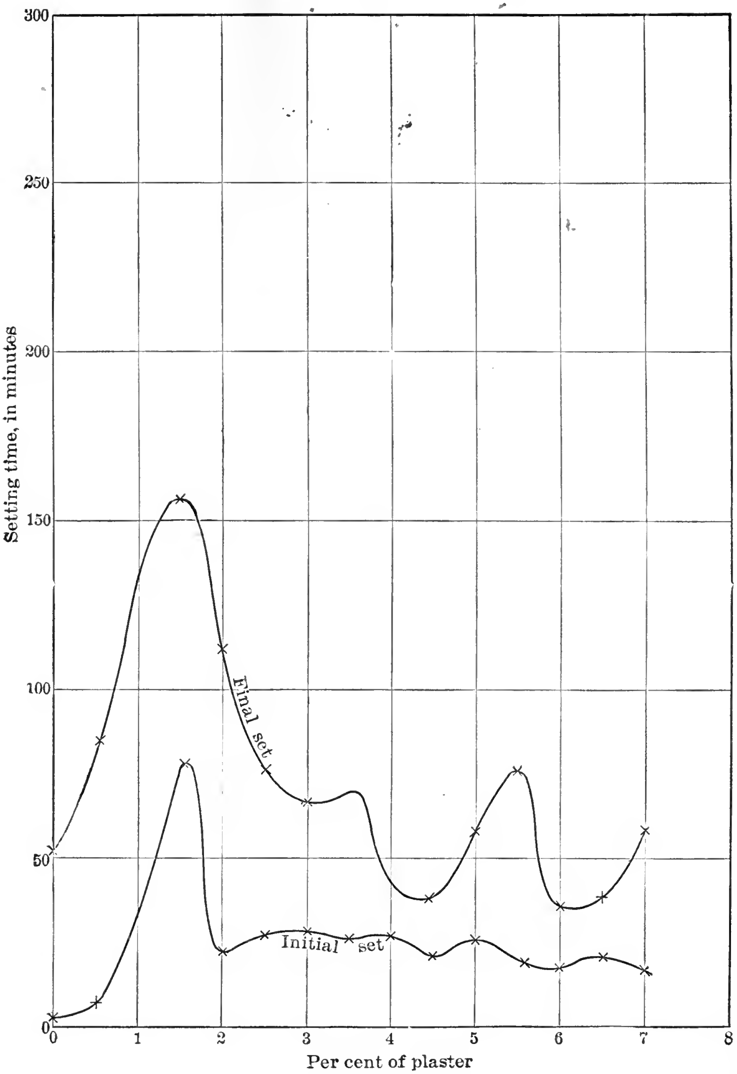

FIG. 137.—Effect of plaster on setting-time of Portland cement. Kniskern and Gass, 1905.

Effect of calcium sulphate on strength of cement.—In addition to retarding the set of the cement, gypsum or plaster exerts an interesting influence on its strength and, in some cases, its soundness.

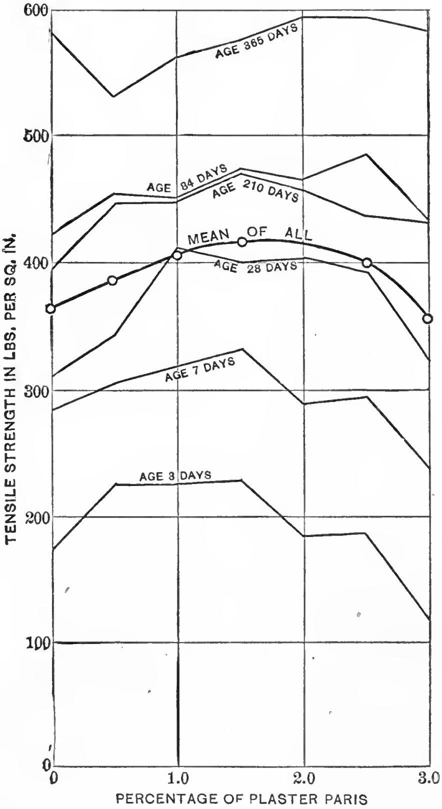

Fig. 138.*—Effect of plaster on strength of 1:3 mortar. (Tetmajer.)

TABLE 201.

EFFECT OF CALCIUM SULPHATE ON STRENGTH OF CEMENT. (DYCKERHOFF.)

Percentage Gypsum.	Time of Set.		Neat Cement.					1 Cement : 3 Sand.				
	Hrs.	Min.	1 Week.	4 Wks.	12 Wks.	25 Wks.	52 Wks.	1 Week.	4 Wks.	12 Wks.	26 Wks.	52 Wks.
0	0	20	323	405	518	620	700	115	168	238	302	360
½	3	30	315	456	572	623	650	142	212	339	353	390
1	10	0	375	508	568	695	780	159	238	311	368	384
2	14	0	425	543	688	718	805	180	263	305	375	410

* From Johnson's "Materials of Construction", p. 187.

TABLE 202.

EFFECT OF CALCIUM SULPHATE ON STRENGTH OF CEMENT. (GRANT.)

Per Cent SO_3 Added.	Neat Cement.				1 Cement : 1 Sand.			
	7 Days.	30 Days.	60 Days.	90 Days.	7 Days.	30 Days.	60 Days.	90 Days.
0	313	500	536	605.4	106.8	159.2	188.4	266.8
½	305	503	567	618.0	129.2	226.6	259.6	255.2

TABLE 203.

EFFECT OF TREATMENT WITH ANHYDROUS CALCIUM SULPHATE. (LEWIS.)

Per Cent Sulphate Added.	Tensile Strength.	
	7 Days: Neat.	7 Days: 3:1.
0	444 lbs.	196 lbs.
2	647 "	
4	663 "	148 "
5	293 "	127 "

TABLE 204.

EFFECT OF TREATMENT WITH CRUDE GYPSUM. (LEWIS.)

Per Cent Gypsum Added.	Tensile Strength.	
	7 Days: Neat.	7 Days: 3:1.
0	444 lbs.	196 lbs.
2	673 "	
3	541 "	179 "
4	533 "	194 "
5	593 "	179 "

TABLE 205.

EFFECT OF TREATMENT WITH PLASTER OF PARIS. (LEWIS.)

Per Cent Plaster Added.	Tensile Strength.	
	7 Days: Neat.	7 Days: 3:1.
0	444 lbs.	196 lbs.
1½	589 "	212 "
2	651 "	215 "
3	729 "	225 "
4	524 "	165 "
5	247 "	66 "
6	254 "	63 "

Methods of using gypsum.—From what has been said on preceding pages, it is evident that in Portland-cement manufacture either gypsum or burned plaster may be used to retard the set of the cement. As a matter of fact, gypsum is the form almost universally employed in the United States. This is merely a question of cost. It is true that to secure the same amount of retardation of set it will be necessary to add a little more of gypsum than if burned plaster were used; but, on the other hand, gypsum is much cheaper than burned plaster.

The addition of the gypsum to the clinker is usually made before it has passed into the ball mill, kominuter, or whatever mill is in use for preliminary grinding. Adding it at this point secures much more thorough mixing and pulverizing than if the mixture were made later in the process. At some of the few plants which use plaster instead of gypsum, the finely ground plaster is not added until the clinker has received its final grinding and is ready for storage or packing.

Analyses of gypsum used.—The following analyses will serve to illustrate the composition of the crude gypsum and of the calcined plaster used at different American Portland-cement plants.

TABLE 206.

ANALYSES OF GYPSUM USED IN CEMENT-PLANTS.

Silica (SiO_2)	0.32	0.86	5.10	7.26	n. d.
Alumina (Al_2O_3)	0.87	0.36			n. d.
Iron oxide (Fe_2O_3)					n. d.
Lime (CaO)	31.94	30.84	n. d.	n. d.	35.8
Magnesia (MgO)	0.52				
Sulphur trioxide (SO_3)	44.93	43.60	40.20	43.20	43.6
Carbon dioxide (CO_2)					
Water	20.95	21.68	n. d.	n. d.	20.3

TABLE 207.

ANALYSES OF CALCINED PLASTER USED AT CEMENT-PLANTS.

Silica (SiO_2)	0.83	1.10	n. d.
Alumina (Al_2O_3)	0.46	0.32	n. d.
Iron oxide (Fe_2O_3)			
Lime (CaO)	38.58	37.87	37.26
Magnesia (MgO)	0.50	0.73	1.11
Sulphur trioxide (SO_2)	54.12	53.26	50.50
Carbon dioxide (CO_2)	n. d.	n. d.	3.40
Water	5.61	6.32	5.50

Effect of various salts on set of cement.—Experiments have been made on the use of various other salts—sulphates, phosphates, chlorides, etc.—by different chemists. Few of the results thus obtained are of any practical importance, for most of the salts experimented with are too costly for use.

Table 208.

Effect of Various Salts on Set of Cement. (Nihoul and Dufossez.)

	Initial Set.		Final Set.	
	Hrs.	Min.	Hrs.	Min.
Pure cement	0	8	0	13
Cement with 2 per cent calcium sulphate	2	7	6	32
" " 2 " " strontium sulphate	0	3	0	5
" " 2 " " barium sulphate	0	3	0	4
" " 2 " " calcium phosphate	0	8	0	18
" " 2 " " " aluminate	0	1	0	3
" " 2 " " precipitated silica	0	5	0	6½

Recent experiments on the use of solid chloride of lime as a retarder have been published by Carpenter. These were carried out by the same experimenters, and probably on the same cement which, when treated with gypsum, gave the erratic results noted on p. 541. Carpenter summarizes * these experiments as follows:

"Messrs. Kniskern and Gass, in the Sibley Laboratory, ground different percentages of chloride of calcium ($CaCl_2$) with cement clinker and afterwards made pats, using in each case simply enough water to give the material its normal consistency for this purpose. Their results show that the chloride of calcium had great effect in retarding the time of setting and exerted the greatest effect when about 0.5 per cent by weight of the chloride of calcium was employed. On account of the water required, 1 per cent of the chloride of calcium would correspond approximately to gauging with a solution of 30 grams per liter in the previous experiments quoted.

$CaCl_2$ Ground Dry with the Clinker.

Per Cent of $CaCl_2$.	Per Cent of Water.	Initial Set, Minutes.	Final Set, Minutes.
0.0	29.8	2	52
0.5	34.1	115	274
1.0	29.8	160	272
1.5	26.4	167	234
2.0	25.4	127	212
2.5	26.4	103	180
3.0	26.4	45	182
3.5	26.4	97	185
4.5	28.6	63	150
5.0	29.8	73	160
5.5	29.8	76	84
6.0	29.8	68	145

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* Engineering News, vol. 53, pp. 13–14. Jan. 5, 1905

"The experiments quoted indicate that chloride of calcium added in small percentages either to the ground clinker as a powder or mixed with the water for gauging has an important effect in extending the time of setting of Portland cement, and so far as the investigations which are accessible show it does not have any detrimental effect on the permanent strength and hardness.

"Chloride of calcium is a deliquescent material which rapidly absorbs moisture, and it is possible that if ground dry with the Portland-cement clinker, even to the amount of ½ per cent, it would cause the material to gather dampness and thus have a bad effect. The chloride of calcium solution can be added readily by adding it to the water used in gauging, since it dissolves with extreme rapidity. The experiments indicate that the set can be controlled by using less than ½ per cent, which would be something less than 2 lbs. to the barrel of Portland cement. Investigations are still necessary for determining whether the effect of chloride of calcium added to the cement before grinding is permanent in its effects, and whether if ground with the cement clinker it would avert any detrimental effect."

List of references on use of calcium sulphate, chloride, etc.

Candlot. Ciments et chaux hydrauliques.

Carpenter, R. C. Recent experiments with materials which retard the activity of Portland cement. Engineering News, vol. 53, pp. 13-14. Jan. 5, 1905.

Deval, L. Composition of sulpho-aluminate of lime (in hydraulic cements). Bull. de la Soc. d'Encourag. l'Ind. National, vol. 5, pp. 49–54. 1900. Abstract in Journ. Soc Chem. Industry, vol. 19, pp. 247–248.

Deval, L. Action of sulphate of lime on cements. Bull. de la Soc. d'Encourag. l'Ind. National, no. 101, p. 784–787. 1901. Abstract in Journ. Soc. Chem. Industry, vol. 21, p. 257.

Deval, L. Influence of calcium sulphate on cements. Thonindustrie Zeitung, vol. 26, p. 913–915. 1902. Abstract in Journ. Soc. Chem. Industry, vol. 21, pp. 971-972.

Lewis, F. H. Specifications for Portland cements and cement mortars. Proc. Engrs Club, Phila., vol. 11, pp. 310–346. 1894.

Ljamin, N. Abnormalities in the initial setting of cement. Thonindustrie Zeitung, vol. 26, pp. 874–876. 1901. Abstract in Journ. Soc. Chem. Industry vol. pp. 972–973.

Nihoul, E., and Dufossez, P. Note on the retardation of setting of Portland cement. Bull. Scient. de l'Assoc. des Elèves des Ecoles spéciales de Liége, no. 3. Abstract in Journ. Soc. Chem. Industry, vol. 21, pp. 859–860.

Rohland, P. Hydration of Portland cement. Zeits. angew. Chemie, vol. 16, pp. 1049–1055. 1903. Abstract in Journ. Soc. Chem. Industry, vol. 22, pp. 1244–1245.

Storage, Packing, and Market.

Necessity for storage.—A twofold necessity exists for large storage space at a modern cement-plant. The cement will in many cases be improved by storage, particularly if it can be so stored that air will gain access to the mass. Aeration in the storage building is, however, rarely possible; and in consequence the tendency now is in the direction of aerating or slaking the clinker *before* grinding. The main reason for storage still remains prominent. It is caused by the fact that while the average mill runs twelve months in a year, the cement-selling period, in most of the United States, is practically confined to six months or even less. This of course necessitates very extensive storage facilities—enough to hold at least three months' output of the mill, and preferably to hold six months' production. This means that for each kiln in a dry-process plant, storage space for at least 20,000 barrels should be provided. As Portland cement dumped from a conveyor will pile up so as to weigh about 90 to 100 lbs. per cubic foot, the storage space above stated (20,000 barrels) would be equivalent to about 80,000 cubic feet for each kiln in the plant. This is the minimum of space that can be given with safety, and an allowance of 150,000 cubic feet per kiln would be much better for the average plant in the Middle or Eastern States. In the South and West conditions are different, and much less storage space is required.

Designs of storage buildings and bins.—In Figs. 139, 140, 141, and 142 are given plans of several recently erected storage buildings and bins. Those shown in Fig. 139 are concrete-steel bins erected for the Portland-cement plant of the Illinois Steel Co.

The stock-house and bins shown in Figs. 140, 141, and 142 are those of the Hudson Portland Cement Co. In a description of that plant accompanying these figures * the following data are given: "The stock-house is a structure 410 feet long and 105 feet wide, having as foundations a series of concrete walls founded on piles. It contains three groups of twenty bins each. The bins are of wood, their walls being laid up solid of 2″×10″ and 2″×8″ plank laid flat and spiked together. The total capacity of the bins is 200,000 barrels of cement. Cement is conveyed to the stock-house from the mill by means of conveyor 26, which discharges into the boot of elevator *O*. This elevator discharges into the transverse screw conveyor 27, which spouts onto two belt conveyors

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* Engineering News.

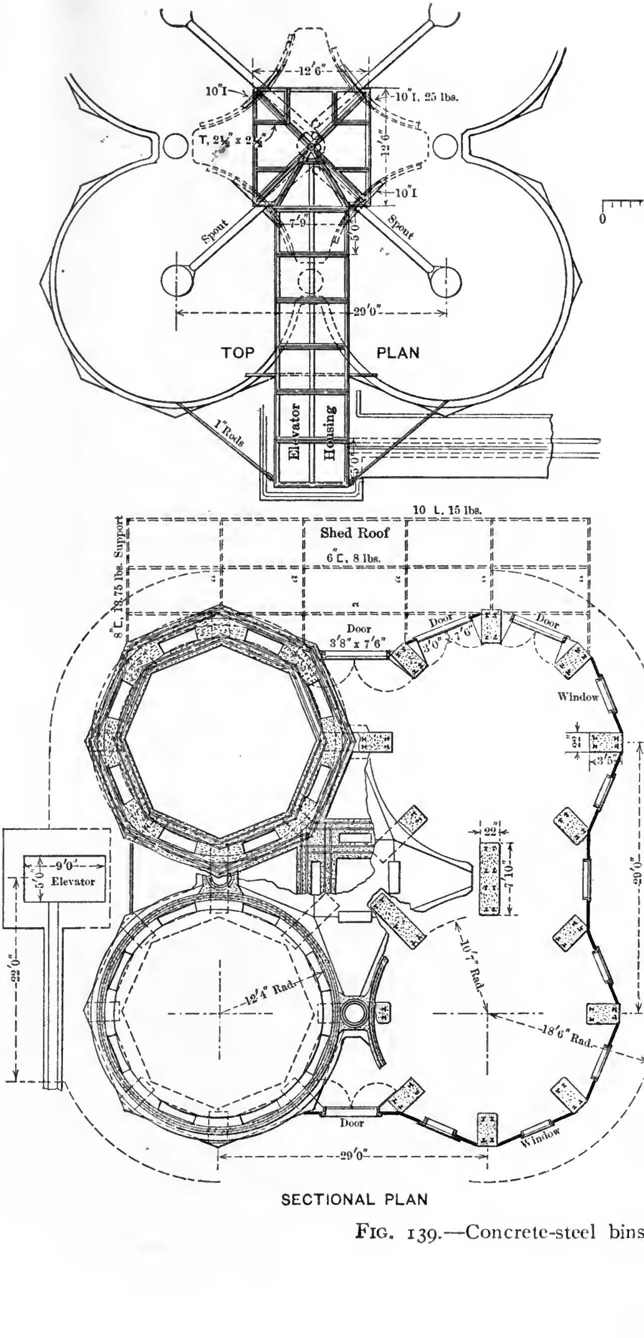
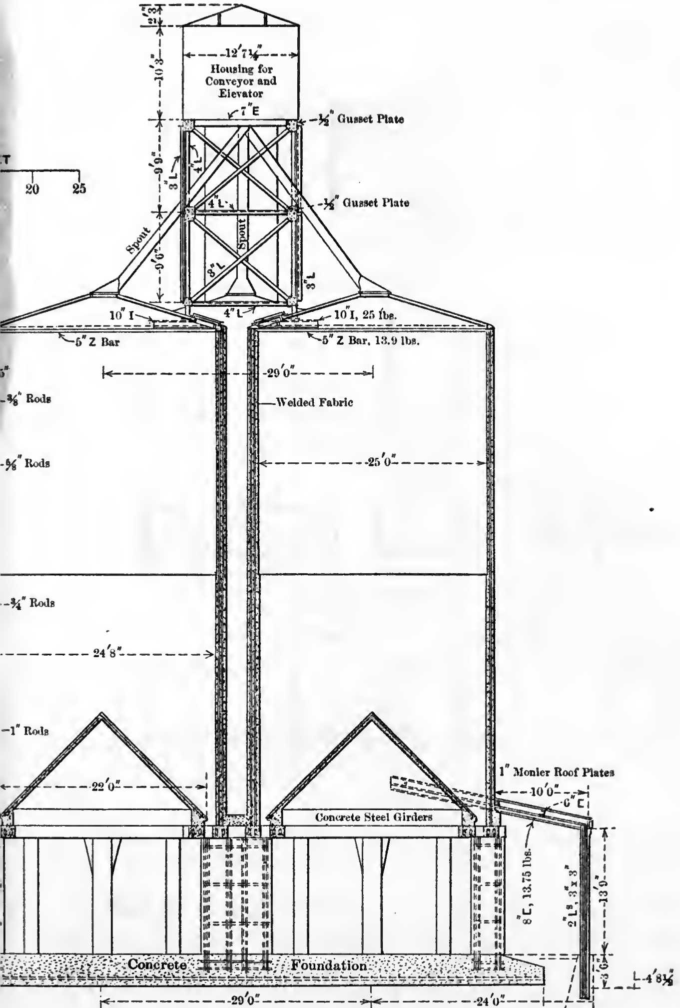


FIG. 139.—Concrete-steel bins



teel Co. (Engineering News.)

[*To face p. 548.*

running lengthwise of the building over the bins. From these belts the cement can be deflected into any one of the 60 bins."

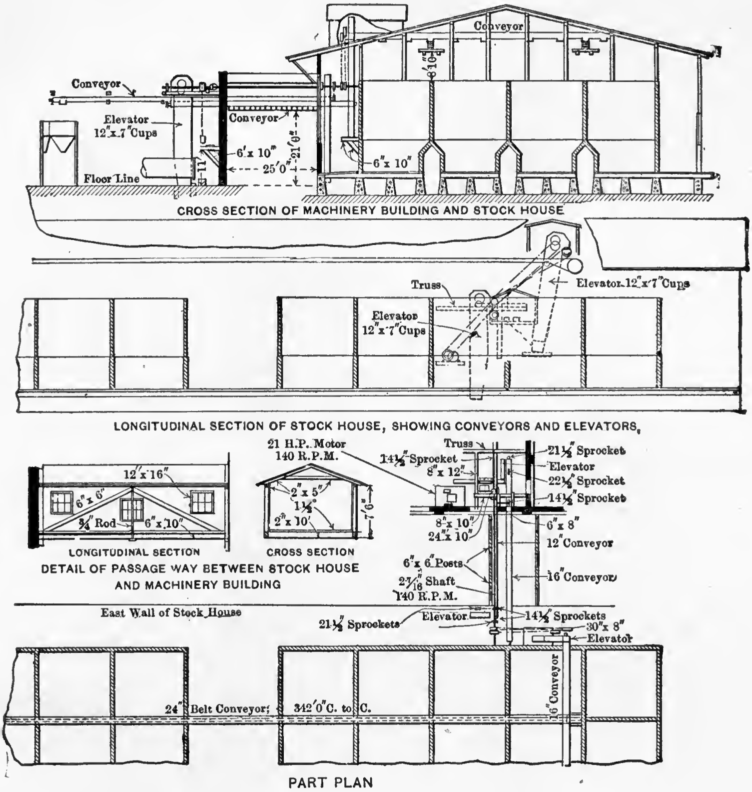


FIG. 140.—Plan and sections of stock-house, Hudson Portland Cement Co., showing conveying machinery. (Engineering News.)

Testing at the mill.—The contents of each bin should be sampled as soon as it is filled, and the usual physical tests made on these samples, supplemented by analysis if need be. If the cement is weak or unsound, it is far better in every way to detect it at the mill than to run the risk of having it rejected at the work. The results of these tests are then forwarded to the purchaser with each shipment, typical blanks for this purpose being shown on page 550.

Of recent years it has become the fashion, in specifications for cement for important work, to require that the purchaser should be represented at the cement-mill by an inspector during the manufacture and shipment of the cement covered by the specifications. This practice, if

Form 18.

Wolverine Portland Cement Co.

TEST CARD.

Order No. .... Quincy, Mich. ....190...
Car No. .... Car, initial ....
Shipped to ....
..................Barrel in paper. ....Barrels in duck. ....Barrels in cooperage.
Fineness, per cent, through No. 100 sieve. .... Pat test, 6 hours steam..........................
Fineness, per cent, through No. 200 sieve. ....
Tensile strength, breaking test in pounds per square inch:
Neat cement (22 per cent water), 1 day. ....
" " (22 " " "), 7 days. ....
" " (6 hours steam) ....
Cement with three parts sand (9 per cent water), 7 days. ....
Cement with three parts sand (6 hours steam at 120 pounds pressure). ....
Initial set with Vicat needle. ....
Temperature. ....
Final set. ....

....
Chemist.

Peninsular Portland Cement Co.

PHYSICAL TEST.

Lot No. ....
Bin No. .... Date. ....190...
To. ....
Car No. ....
Fineness on 100-mesh sieve. .... Boiling test. ....
Setting-time, initial ....

		24 Hours	7 Days
Tensile strength,	neat.	....	....
" "	1 cement, 3 sand.	....	....

....Chemist.

taken up in a proper spirit by both sides, will prevent many difficulties and misunderstandings.

If the duties of such an inspector are to be properly carried out, however, he should possess a somewhat intimate knowledge of the processes of cement manufacture. The position is, moreover, one of extreme delicacy, and it offers abundant opportunity for bribery on the one side and blackmail on the other. For these reasons it is obvious that a mill-inspector must be a man of special training and qualifications and unimpeachable integrity. As a matter of fact, such men are rarely obtainable for this position, and the inspector is usually a young engineer, with but little knowledge of the points which it is necessary to guard against.

Packing.—According to the recently issued specifications of the American Society for Testing Materials, quoted later, Portland cement should be packed in bags of 94 lbs. net weight, four of which make a barrel of 376 lbs. net. Several other important specifications require a barrel of 375 lbs. net. In ordinary calculations it is often assumed for convenience that a barrel of Portland cement weighs 400 lbs. gross or 380 lbs. net. The following table (209), published some years ago by Mr. Sanford Thompson,* gives the results of a series of actual tests on the weight, size, etc., of cement barrels.

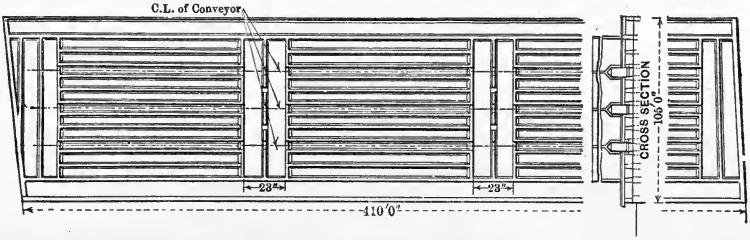


Fig. 141.—Foundation plan of cement stock-house, Hudson Portland Cement Co.

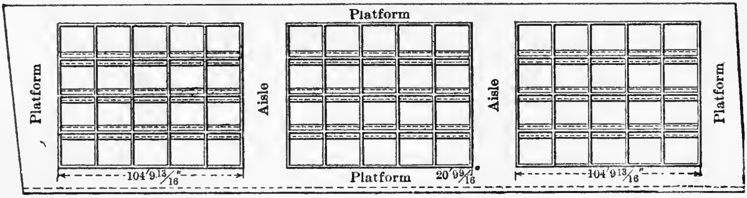


Fig. 142.—Plan of bins in cement stock-house, Hudson Portland Cement Co.

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[*] Thompson, Sanford E. Weights of Portland cement and capacity of cement barrels. Engineering News, Oct. 4, 1900. For a more detailed discussion of the subject, reference should be made to Taylor and Thompson's "Concrete, Plain and Reinforced", 1905, pp. 216 et seq.

TABLE

CAPACITY OF PORTLAND-CEMENT BARRELS AND

Number Barrels Tested; Results Averaged.	Brand.	Height between Heads, Feet.	Average.		Capacity Barrel between Heads, Cu. Ft.	Depression, Cement below Head, Feet.	Volume of Depression, Cu. Ft.
			Diameter of Barrel, Feet.	Horizontal Area, Sq. Ft.			
6	Giant.	2.19	1.430	1.605	3.495	0.12	0.171
6	Alsen.	2.08	1.403	1.546	3.219	0.04	0.059
3	Saylor's.	2.07	1.412	1.571	3.249	0.07	0.096
5	Dyckerhoff.	2.01	1.407	1.554	3.123	0.07	0.093
1	Fiske Lion *	2.13	1.38	1.496	3.186	0.03	0.039
5	Atlas.	2.12	1.437	1.622	3.446	0.17	0.235
5	Aalborg †.	2.01	1.455	1.662	3.327	0.10	0.148
	Final averages.	2.09	1.418	1.579	3.292	0.09	0.120

* Hanover. † Denmark. § Partial averages. To be compared only

At present a very large proportion of American cement is marketed in sacks or bags, packing in wood being almost entirely confined to cement intended for export or coastwise shipment. Foreign cement, of course, reaches the American market in barrels, but imported cements are becoming of less consequence each year.

When cement is packed in wood, the barrels are usually charged for at a rate sufficient to give a slight profit to the packing department of the mill. Bags and sacks are also charged extra, with a rebate for returned bags. In figuring the cost of cement manufacture it is therefore unnecessary to include the actual cost of the packages, but the labor and power used in the packing-house must be figured in.

209.

WEIGHT OF CONTENTS. (HOWARD A. CARSON.)

Volume of Cement per Barrel.			Net Weight of Cement per Barrel at Dumping.		Weight per Cubic Foot.				Weight of Barrel, Pounds.
Packed, Cu. Ft.	Loose, Cu. Ft.	Shaken, ‖ Cu. Ft.	Before, Pounds.	After, Pounds.	Packed, Pounds.	Loose, Pounds.	Shaken, Pounds.	Sifted, Pounds.	
3.347	4.173	....	381.0	....	113.81	91.38	....	......	29.0
3.161	4.192	....	374.2	....	118.45	89.20	....	......	24.3
3.152	4.052	....	387.0	....	122.75	94.24	....	......	22.7
3.031	3.989	3.522	373.2	371.4	123.16	93.18	105.54	......	25.6
3.147	4.270	3.695	378.0	378.0	120.11	88.52	102.29	......	22
3.211	3.754	3.432	377.4	376.9	117.54	100.49	109.45	90.6	21.1
3.206	4.058	3.598	370.7	370.2	115.71	91.40	102.94	80.3	23.3
3.179	4.070	3.562§	377.4	374.1§	118.79	92.63	105.06§	85.4§	24.0

with like brands.

‖ Box rocked over bar.

Note.—Paper weighs about 1 lb.

CHAPTER XXXVII.

COSTS AND STATISTICS

Costs of Manufacture of Portland Cement.

To the popular mind the manufacture of Portland cement is, though somewhat mysterious in process, so remarkably cheap as to be a very attractive investment. This opinion is carefully fostered for selfish purposes by many so-called "cement experts" and "cement engineers", men of a class comparable with the "mining experts" who infest the Western mining districts and differing in degree only, not in kind, from the more humble green-goods man of the East. Michigan, especially, has been the prey of this class of cement experts, for in no other State has so much money been sunk by comparatively poor people in the erection of unprofitable Portland-cement plants. Many of these companies have been reorganized and are now on a firm basis, but the amount of money thrown away by ignorant investors, misled by lying estimates and prospectuses, has been enormous.

The truth of the situation appears to be, on the contrary, that there is a very small margin of profit for most of the plants now engaged in Portland-cement manufacture. It is probable, indeed, that the percentage of profit in the lime or natural-cement industries is far greater than in the average Portland-cement plant.

In the following pages some estimate of the cost of Portland-cement manufacture under various conditions will be given.

Factors of cost.—The total cost of manufacture of Portland cement may be subdivided as follows:

A. Fixed charges.

(*a*) Interest on cost of land and quarries;
(*b*) Interest on cost of construction and erection;
(*c*) Interest on reserve capital invested;
(*d*) Allowance for sinking fund;
(*e*) Insurance and taxes.

B. Current administrative expenses.
  (*a*) Salaries of administrative officers;
  (*b*) Expenses of sales and advertising department.

C. Current factory costs.
  (*a*) Raw materials
    1. Cement materials;
    2. Coal;
    3. Gypsum;
  (*b*) Supplies and repairs;
  (*c*) Labor;
  (*d*) Mill-office and laboratory expenses.

Cost of land and quarries.—The cost of land, including under this head both the land on which to locate the plant and also the land containing the supplies of raw material, is naturally the most variable item of the lot. Much will depend on the manner in which the negotiations are conducted. When marl lands are hunted with the aid of a brass band and a press bureau prices as high as $40 per acre (containing about 9 feet of workable marl) have been paid. On the other hand, lands located on transportation routes and underlaid by 40 feet of limestone and more than enough shale have been purchased as farming land at about $5 per acre, the seller concealing from the guileless purchaser the fact that the soil was too thin for good farming. In the Lehigh district, where little cement land remains unbought, prices varying from $100 to $500 per acre have been quoted, but I have no means of determining the true *average* value of land in this district.

Examination of a number of prices paid for land by cement-plants shows that, considering both area and workable thickness, the price paid usually falls between $\frac{1}{4}$ and $\frac{1}{10}$ cent per cubic yard of raw material. Land for the plant itself may be expensive, for good mill-sites are scarce.

In this connection it may be well to recall some estimates previously made on the amount of raw material required by a plant. It was stated that each kiln of a dry-process plant will use about 190,000 cubic feet of limestone per year, equal to a thickness of $4\frac{1}{2}$ feet over an acre, plus 80,000 cubic feet of shale or clay, equivalent to an acre 2 feet thick. A wet-process plant will use about 450,000 cubic feet of marl (measured in place) plus about 45,000 cubic feet of clay or shale. In buying quarry lands for a new plant, at least a twenty-year supply of workable raw material should be secured.

Cost of equipment and erection.—Exclusive of the cost of land, the cost of equipping and erecting a good plant will usually fall within the limits of $50,000 to $80,000 per kiln. These limits may seem wide, but it is difficult to make a closer general estimate. Two plants recently built cost as follows:

4-kiln plant, total cost...	$287,000	Cost per kiln..............	$71,750
6- " " " " ...	373,000	" " "	62,167

For small plants of 2 to 6 kilns each such costs would not be exceptional. For larger plants it is to be remembered that cost per kiln decreases with increase in the number of kilns. The following table of average costs will serve to exemplify this and may be of use as a basis for general estimates:

2-kiln plant............	$70,000 to	$80,000	per kiln
4- " "	60,000 "	70,000	" "
6- " "	50,000 "	60,000	" "
8- " " or over......	45,000 "	50,000	" "

The distribution of this total throughout the plant may be shown by the following estimate for cost of construction of a 6-kiln dry-process plant:

Quarry, track, and trestle..................	$15,000
Crusher and mixing.........................	22,100
Raw and clinker mills......................	63,640
Kiln mill..................................	53,080
Coal mill..................................	15,920
Power-plant................................	63,000
Stock-house................................	25,000
Office, laboratory, etc....................	10,000
	$267,740

Total capital required.—The amount of capital required to properly float a cement proposition is considerably in excess of the costs of land, construction, etc. The principal causes of this condition are:

(*a*) It is within bounds to say that the average cement-plant will not produce a normal cement at a normal cost for a considerable period (varying from 3 to 6 months or even longer) after the plant is first put in operation. Both the machinery and the personnel of the plant will require numberless (though individually small) alterations before good work can be accomplished. The plant must be carried through this profitless and expensive period entirely on its reserve capital.

(*b*) It is becoming more and more the fashion among engineers to judge a cement by its past record, and to refuse bids from a plant not possessing a record of success in actual work. Even after the plant is working normally, therefore, steady sales cannot be counted on for some time. The intervening time can, of course, be devoted to filling large stock-houses, but this brings in no ready money to the plant.

(*c*) Cement is sold on comparatively long time, while many of the expenses of the plant must be paid in cash. This is particularly the case with regard to quarry and mill labor, an item which alone may amount in a six-kiln plant to from $4000 to $6000 per month.

For these reasons it is advisable to make a very liberal allowance for the working capital required. A reserve amounting to $20,000 to $25,000 per kiln will probably be found sufficient to cover most cases, though in commencing work on absolutely new materials a considerably larger reserve will be found advisable. Adding this necessary reserve to the amount required for the purchase of land and the actual erection of the plant, and for ordinary small plants, it will be found that the total working capital necessary will be in the neighborhood of $100,000 per kiln.

Current administrative expenses.—This group of expense factors includes the salaries of the administrative officers of the plant and also the expenses of the sales department, including advertising. It is obviously one of the most variable factors in the cost of cement-manufacture as between different plants. Even at the same plant it may vary widely from time to time, because its total amount does not depend directly upon the amount of cement sold. In a large plant during a prosperous year the costs chargeable to this group of expenses may fall as low as 5 cents per barrel of cement produced, while in a small plant running undertime they may easily rise as high as 15 cents per barrel.

Cost of excavating raw materials.—This point has been covered quite fully on preceding pages. In the present place it will only be necessary to summarize this information by stating that the total cost of raw materials, delivered at the mill, per barrel of cement produced, will usually fall within the following limits:

		Cost per Barrel.		
Cement rock and limestone...	*a.* Limestone on property . .	$0.07	to	$0.10
	b. Limestone purchased . . .	.15	“	.20
Pure limestone and clay.	*a.* Quarried.	.06	“	.15
	b. Mined.	.10	“	.20
Marl and clay or shale.	*a.* Both on property.	.03	“	.05
	b Clay purchased.	.08	“	.15

Total power required.—The total power developed in a Portland-cement plant is not far from 1 H.P. for each barrel of cement turned out per day. As most of the power is required continuously, it is safe to figure on a requirement of 20 to 30 H.P.-hours for each barrel of cement. This will include the power used in grinding and mixing the raw materials in running conveyors, kilns, etc., and in grinding the clinker.

At most American plants all this power is derived from the direct consumption of coal under boilers. At several plants, however, water power is used with electric transmission; in at least one plant natural gas is used, partly in gas-engines and partly under boilers, and in a few plants part of the power is derived from the waste gases of the kilns.

Cost of coal for kilns and power.—The total amount of coal used per barrel of cement, both under the boilers, in driers, and in the kilns, may vary from 170 lbs. in a Lehigh-district plant using long kilns to 300 or 350 lbs. in a wet-process plant. Even this latter figure is exceeded at times, for one wet-process plant recently reported a total coal consumption of over 400 lbs. per barrel.

Cost of gypsum used.—The amount of gypsum or plaster used in a large plant is quite an item, as 8 to 14 lbs. may be used per barrel of cement. Crude gypsum in small lumps may be bought as low as 80 cents or so per ton when the cement-plant is located in a gypsum-producing district. On the other hand, burned plaster plus freight may cost as high as $6 to $10 per ton for a plant not so near the source of supply. Assuming that on the average 10 lbs. of gypsum or plaster are used in each barrel of cement, these prices would make the cost per barrel of cement range from ½ cent to 5 cents. At *most* of the plants in this country the gypsum cost will probably range between 1 and 2 cents per barrel of cement.

Distribution and cost of labor.—The following statement* of the distribution and amount of labor in a six-kiln Lehigh-district plant has recently been published. The number of men given are those actually employed in one twenty-four-hour day (two shifts), and the cost per barrel has been based on an output of 1200 barrels per day.

TABLE 210.

LABOR COSTS IN CEMENT-PLANT.

Location.	Number of Men.	Labor Cost per Barrel.
Stone house	4	$0.005
Raw mill	6	.0075
Coal mill	6	.01
Kiln-room	8	.015
Clinker mill	6	.0075
Boiler-room	4	.0075
Engine-room	4	.0075
Yard gang	13	.015
Repair gang	13	.0225
Packing-house	30†	.04
	94	$0.1375

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* Boilleau and Lyon. Cost of building and operating a Portland-cement plant. Municipal Engineering, vol. 26, pp. 391–395. June, 1904.

† Contract work (estimated).

The total labor costs given in the footing of the above table may profitably be compared with those of two large and admirably managed plants elsewhere. This is done in the following summary:

TABLE 211.

LABOR AND OUTPUT IN TYPICAL PLANTS.

Output per Day.	Process.	Number of Men.	Barrels per Man.	Cost per Barrel.
1200 bbls.	Dry	94	12.78	$0.1375
2800 "	"	159	17.61	.1216
1600 "	Wet	142	11.27	.135

It is to be noted that the second of these plants uses three shifts per day, but its mechanical equipment is so perfect that this does not show in the labor costs.

Estimates of Total Cost per Barrel.

Disregarding the remarkably low estimates of cost to be found in prospectuses, several estimates of better quality have been published within the past few years. These relate to manufacture carried on under very different conditions, two applying to the Lehigh district, with cheap labor and fairly cheap fuel, while a third estimate is for a plant located in perhaps the worst possible spot in the country for fuel, labor, and freight. To these published estimates has been added a table prepared by the present writer.

A partial account * of costs at the Atlas plant was given by Messrs. Stanger and Blount a few years ago. This is as follows:

TABLE 212.

COSTS OF CEMENT MANUFACTURE AT ATLAS PLANT.

	Cost per Ton, English Money.		Cost per Barrel.
	s.	d.	
Raw materials delivered at mill	1	9¾	$0.076
Fuel for power	3	0	.125
Fuel for kiln	3	0	.125
Labor	2	0	.082
Repairs, lubricants, etc.	2	11½	.124
Superintendence, laboratory, and mill-office	1	1¾	.048
	13	11	.58

The following estimate,† recently published by Boilleau and Lyon, is on the basis of a 2000-barrel plant (ten 60-foot kilns) located in the Lehigh district.

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* Proc. Institution Civil Engineers, vol. 145, pp. 65–66. 1901.

† Municipal Engineering, vol. 26, p. 394. June, 1904.

TABLE 213.

DETAILED ESTIMATES OF COSTS OF CEMENT MANUFACTURE (2000-BARREL PLANT).

	Cost Per Barrel.	
Labor:		
Quarry	$0.05	$0.15
Stone house	.00½	
Mill building	.01½	
Kiln-room	.01½	
Engine- and boiler-room	.01½	
Fuel mill	.01	
Yard gang	.01½	
Repair gang	.02¼	
Miscellaneous	.00¼	
Raw materials:		
Coal	.22½	.24¼
Gypsum	.01¾	
Supplies:		
Repair parts	.04	.09
Lubricants	.02	
Miscellaneous	.03	
General mill account.		
Packing and shipping	.04	.06
Office force	.02	
Fixed charges:		
Interest on cost of plant	.07	.23½
Sinking fund	.05	
Depreciation	.05	
Administration and selling expenses	.06½	
Total		$0.77¾

Estimates have been published by Mr. E. Duryee, covering the cost of building a small plant and making cement at a very inaccessible point in Arizona. The raw materials are located quite near the plant, but fuel, labor, and freight are all very high. These estimates are as follows:

TABLE 214.

APPROXIMATE COST OF TWO-KILN PLANT, DAILY CAPACITY 300 BARRELS. (DURYEE.)

Crusher	$2,000
Mill for disintegrating clay	500
Rotary clay drier	1,500
Elevators and conveyors for raw materials	1,000
Storage-bins for raw materials	1,000
Mills for grinding raw materials	10,000
Two rotary kilns, linings, and stacks	15,000
Mills for grinding cement	10,000
300-H.P. electric motors and step-down transformers	9,000
Conveyors and elevators for cement	1,500
Cost of grading and erecting machinery	10,000
Shafting and pulleys, belts, and setting up	5,000
Buildings and cement-bins	10,000
Office, laboratory, and laboratory equipment	1,500
Freight	10,000
Plans, specifications, and superintendence	3,000
	$91,000

"With such a mill, and using charcoal for burning cement, the cost of manufacture would be approximately as follows, allowing for power only the proportion necessary for maintaining and operating the electric plant provided":

	Per Barrel.
Labor and superintendence	$0.70
Raw materials	.30
Fuel for burning	.90
Power (maintenance and operation only)	.05
Repairs and sundries	.05
	$2.00

This estimate is of interest in connection with the possible erection of plants at various points in Spanish America, where similar conditions may be encountered.

The following general estimates have been prepared embodying the data presented on pages 554 to 559. It will be seen that they apply, except for the second and fifth cases, to very small plants, and that the totals are correspondingly high.

TABLE 215.

ESTIMATES OF AVERAGE COST OF PORTLAND-CEMENT MANUFACTURE.

Materials	Limestone and clay	Cement rock and limestone	Marl and clay	Marl and clay	Marl and clay
Process	Dry	Dry	Dry	Wet	Wet
Number of kilns	4	8	4	4	8
Size of kilns	60 feet	80 feet	60 feet	60 feet	100 feet
Output per day	700 bbls.	2000 bbls.	600 bbls.	400 bbls.	1100 bbls.
Cement materials	0.08	0.08	0.03	0.03	0.03
Power coal	0.08	0.08	0.09	0.13	0.11
Drier coal at $2	0.02	0.01	0.07	0.00	0.00
Kiln coal	0.12	0.10	0.14	0.20	0.15
Labor	0.12	0.10	0.16	0.20	0.15
Supplies, etc	0.15	0.11	0.15	0.16	0.12
Office and laboratory	0.05	0.03	0.05	0.05	0.04
Admin. and sales	0.08	0.05	0.10	0.13	0.09
Interest, etc	0.16	0.12	0.20	0.26	0.20
	0.86	0.68	0.99	1.16	0.89

Statistics of the American Portland-cement Industry.

Statistics relative to the growth of the Portland-cement industry in the United States will be found serviceable for many purposes, and certain data on this point have been accordingly incorporated in the present chapter.

Total production and growth of the industry.—The following table has been prepared to illustrate the growth of the American Portland-cement industry, from its inception to the present day, in regard to number of plants, annual output, and value of product. The data used in compiling this table are taken in large part from the annual report on mineral resources issued by the United States Geological Survey. For the years prior to 1890 the figures are to be regarded as merely rough approximations to the truth, but in later years they may be accepted as practically correct.

TABLE 216.

TOTAL PRODUCTION OF PORTLAND CEMENT IN THE UNITED STATES.

Years.	Barrels.	Value.	Plants.
1870–1880...	82,000	$246,000	
1880........	42,000	126,000	
1881........	60,000	150,000	
1882........	85,000	191,250	
1883........	90,000	193,500	
1884........	100,000	210,000	
1885........	150,000	292,500	
1886........	150,000	292,500	
1887........	250,000	487,500	
1888........	250,000	487,500	
1889........	300,000	500,000	
1890........	335,500	704,050	16
1891........	454,813	967,429	17
1892........	547,440	1,153,600	16
1893........	590,652	1,158,138	19
1894........	798,757	1,383,473	24
1895........	990,324	1,586,830	22
1896........	1,543,023	2,424,011	26
1897........	2,677,775	4,315,891	29
1898........	3,692,284	5,970,773	31
1899........	5,652,266	8,074,371	36
1900........	8,482,020	9,280,525	50
1901........	12,711,225	12,532,360	56
1902........	17,230,644	20,864,078	65
1903........	22,342,973	27,713,319	71
1904........	26,505,881	23,355,119	75
	106,114,077	$124,660,717	

Production of Portland cement by States, 1901–1903.—In the table on the page opposite, which is slightly revised * from one published by L. L. Kimball in the "Mineral Resources of the U. S. for 1903", the Portland-cement production of the separate States is given for the years 1901, 1902, and 1903.

In such States as have but a single plant their production is combined with that of another State, in order that the separate figures of any plant shall not be revealed. In this table the Portland-cement

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* The revision is the correction, in the third column from the right, of the number of plants in 1903, which in the original was evidently incorrect.

TABLE 217.

PRODUCTION OF PORTLAND CEMENT IN THE UNITED STATES IN 1901, 1902, AND 1903, BY STATES.

State.	1901.			1902.			1903.		
	Number of Works.	Quantity, Barrels.	Value.	Number of Works.	Quantity, Barrels.	Value.	Number of Works.	Quantity, Barrels.	Value.
Alabama	......	......	......	1	......	......	1		
Arkansas	1	......	......	1	......	......	1		
California	1[3]	146,848	$513,968	2[3]	294,156	$431,910	3	631,151	$1,019,352
Colorado	1[4]	585,000	643,500	2	82,044	105,016	1	258,773	436,535
Georgia	......	......	......	1	......	......	1		
Illinois	4	528,925	581,818	4	767,781	977,541	4	1,257,500	1,914,500
Indiana	2	218,402	240,242	3	536,706	628,244	3	1,077,137	1,347,797
Kansas	1	......	......	1[2]	830,050	1,017,824	1	1,019,682	1,285,310
Michigan	10	1,025,718	1,128,290	10	1,577,006	2,134,396	13	1,955,183	2,674,780
Missouri	......	......	......	1	......	......	2	825,257	1,164,834
New Jersey	3	1,612,000	1,450,800	2	2,152,158	2,563,355	3	2,693,381	2,944,604
New York	7	617,228	617,228	10	1,156,807	1,521,553	10	1,602,946	2,031,310
Ohio	7[5]	689,852	758,837	7	563,113	685,571	8	729,519	998,300
Pennsylvania	13	7,091,500	6,382,350	15	8,770,454	10,130,432	16	9,754,313	11,205,892
South Dakota	1	......	......	1	......	......	1		
Texas	2[6]	195,752	215,327	2	165,500	234,950	1		
Utah	1	......	......	1	......	......	1		
Virginia	1	......	......	1[1]	334,869	433,286	1	538,131	690,105
West Virginia	......	......	......	......	......	......	1		
Total	56	12,711,225	12,532,360	65	17,230,644	20,864,078	71	22,342,973	27,713,319

[1] Includes product of the single plants in Alabama and Georgia.
[2] " " " " " " " Missouri and South Dakota.
[3] " " " " " plant " Utah.
[4] " " " " only Portland-cement plant in Kansas.
[5] " " " " " " " " Virginia.
[6] " " " " single plant in South Dakota.

product in 1903 of the only plant in Alabama which produces that variety of cement is combined with the product of the plants in Georgia, Virginia, and West Virginia. The plants in Missouri and Arkansas have their products combined; those in Kansas and Texas, and those in Utah, South Dakota, and Colorado also show combined products, and in each case the result is given in connection with the State which was the largest contributor to the total product.

Production in the Lehigh district, 1890–1903.—The following table has been prepared by the writer to illustrate the position held by the Lehigh district of Pennsylvania–New Jersey:

TABLE 218.

PORTLAND-CEMENT PRODUCTION OF THE LEHIGH DISTRICT, 1890–1903.

Year.	Lehigh District.		Entire United States.			Percentage of Total Product Manufactured in Lehigh District.
	Number of Plants.	Number of Barrels.	Number of Plants.	Number of Barrels.	Value.	
1890......	5	201,000	16	335,500	$439,050	60.0
1891......	5	248,500	17	454,813	1,067,429	54.7
1892......	5	280,840	16	547,440	1,152,600	51.3
1893......	5	265,317	19	590,652	1,158,138	44.9
1894......	7	485,329	24	798,757	1,383,473	60.8
1895......	8	634,276	22	990,324	1,586,830	64.0
1896......	8	1,048,154	26	1,543,023	2,424,011	68.1
1897......	8	2,002,059	29	2,677,775	4,315,891	74.8
1898......	9	2,674,304	31	3,692,284	5,970,773	72.4
1899......	11	4,110,132	36	5,652,266	8,074,371	72.7
1900......	15	6,153,629	50	8,482,020	9,280,525	72.6
1901......	16	8,595,340	56	12,711,225	12,532,360	67.7
1902......	17	10,829,922	65	17,230,644	20,864,078	62.8
1903......	17	12,324,922	71	22,342,973	27,713,319	55.1

Imports of cement, 1899–1903.—The imports of cement into the United States in 1899 to 1903 inclusive, by countries, were as follows:

TABLE 219.

IMPORTS OF HYDRAULIC CEMENT INTO THE UNITED STATES IN 1899, 1900, 1901, 1092, AND 1903, BY COUNTRIES.

Country.	1899.	1900.	1901.	1902.	1903.
	Barrels.	Barrels.	Barrels.	Barrels.	Barrels.
United Kingdom......	199,633	267,921	37,390	79,087	146,994
Belgium.............	624,149	826,289	303,180	615,793	737,576
France..............	15,649	32,710	11,771	14,922	14,865
Germany.............	1,193,822	1,155,550	555,038	1,259,265	1,377,414
Other European countries.............	68,348	75,827	19,077	17,956	27,415
British North America..	4,398	4,517	6,066	3,611	4,421
Other countries.......	2,389	23,869	6,808	4,153	9,265
Total.........	2,108,388	2,386,683	939,330	1,994,787	2,317,950

"The figures used in compiling this table are those which show the total imports. In 1903 England stands third in the list of foreign countries which sent cement to America. From 1871 to 1876 nearly all importations of foreign cement were from England. In the four years following Germany gradually assumed an important place as rival, and in 1882, while England sent one half the cement exported to the United States, Germany sent three fourths of the remainder. Ten years later Germany was the leading foreign country sending cement to America, and since then has held that position."

CHAPTER XXXVIII.

CONSTITUTION, SETTING PROPERTIES, AND COMPOSITION OF PORTLAND CEMENT.

Limitations of chemical analyses.—An ordinary chemical analysis of a specimen of cement will determine what elements are present in the cement, and in what percentages these various constituents are represented. The comparison of a long series of such analyses, such as is presented later in this chapter, will enable certain conclusions to be drawn as to the probable limits of composition of good Portland cements; and an analysis of a single cement may show that it contains undesirable ingredients or that inert material is present in undesirable quantity. But these methods of investigation fail to give the least information concerning the real *constitution* of Portland cement as distinguished from its *composition;* they give no information whatever as to the manner in which the various elements are combined among themselves. They fail, moreover, to give any clue to the reason why certain mixtures give good cements, while others give weak or unsound products; and they afford no explanation of the "hydraulic" or setting properties which the powdered clinker possesses. It is evident, therefore, that other methods of investigation must be adopted, since even the most careful chemical analysis fails to aid us in this line of research.

Constitution and Setting Properties.

Available methods of investigation.—Two distinct methods of investigation are available—microscopic and synthetic.

The first has been applied with great success by geologists to the study of the igneous rocks, and as cement clinker is practically an artificial (though very basic) igneous rock, the microscope can be used successfully in its examination. By grinding normal clinker of known analysis down to thin transparent slices, the microscope is able to detect certain constituents common to all good clinkers. The next step, of course, is to determine the composition of these different constituents, and here the synthetic method is applicable.

In synthetic work pure lime, silica, alumina, etc., are mixed in certain definite proportions and burned to a clinker. The hydraulic properties of this clinker can be examined by powdering part of it and testing the resulting cement. Examination under the microscope will fix certain optical characters peculiar to each clinker composition, and the data thus obtained can be used to determine the constituents of commercial-cement clinker, as noted in the preceding paragraph.

Synthetic investigations.—Richardson has recently summarized the results of his own studies and those of previous observers as follows:

"The preparation of synthetic silicates and aluminates which might exist in Portland cement was carried out to a certain extent by Le Chatelier and the Newberrys, but in neither case were these compounds characterized completely, especially as to their optical properties. This has been done by the writer within the last two years, and the optical properties and other characteristics of the following definite silicates and aluminates have been determined.

"Monocalcic silicate (SiO_2CaO): A crystalline substance of high optical activity and little or no hydraulic properties. Specific gravity 2.90.

"Dicalcic silicate (SiO_22CaO, or more probably $2SiO_24CaO$): A definite crystalline compound of high optical activity and of very little hydraulic activity except in the presence of carbonic acid, but setting slowly in water, generally lacking volume constancy. Specific gravity 3.29.

"Tricalcic silicate (SiO_23CaO): A definite crystalline silicate of low optical activity and corresponding in this respect with alit. Its hydraulic activity is not great, but greater than that of dicalcic silicate. If fused and reground it sets slowly like Portland cement. Specific gravity 3.03.

"Three definite silicates of calcium, therefore, appear to exist, the two more basic ones being strongly differentiated from each other by their optical activity.

"Monocalcic aluminate (Al_2O_3CaO): This aluminate is a crystalline substance of high optical activity, but is not sufficiently basic to permit of its existence in a material of such basic character as Portland-cement clinker. Specific gravity 2.90.

"Tricalcic dialuminate ($2Al_2O_33CaO$): This aluminate is one of highly crystalline character and of great optical activity, making it readily recognizable. Specific gravity 2.92.

"Dicalcic aluminate (Al_2O_32CaO): A substance crystallizing from a state of fusion in dendritic forms having no optical activity and being, therefore, isotropic. This differentiates this aluminate very sharply from the preceding one and makes the identification of the two materials very easy. Specific gravity 2.79.

"Tricalcic aluminate (Al_2O_33CaO): This aluminate crystallizes from the fused condition in elongated octahedra. It is isotropic and it might at first be assumed that it was not a definite compound, but merely the dicalcic aluminate crystallizing out of a magma of indefinite composition. It has been shown, however, by further investigations too lengthy to go into at this point, to be undoubtedly a definite aluminate. Specific gravity 2.91.

"Definite compounds of iron and lime and alumina and magnesia have also been shown to exist, but their consideration here is unnecessary, as the constitution of Portland cement can be better discussed, theoretically, by a study of clinker, into which these elements do not enter.

"Among the theories advanced as to the constitution of Portland cement there are those which assume the presence of certain so-called silico aluminates, such as $2SiO_2$, $2Al_2O_3$, 6CaO, and others of less basic form. All of these proposed compounds have been prepared by the writer and found not to be definite chemical compounds nor to correspond in any way with any of the mineral entities found in industrial clinker. They are in fact only solid solutions, of aluminates in silicates, of indefinite structure."

Microscopic investigations.—Le Chatelier, Törnebohm, and Richardson have studied both industrial and synthetic clinker under the microscope, and the results of these preliminary studies have thus been summarized by the last-named investigator:

"By this method of study Le Chatelier, and, at the same time independently of him, Törnebohm identified in Portland-cement clinker four distinct mineral constituents which Törnebohm described as follows, naming them Alit, Belit, Celit, and Felit:

"Alit is the preponderating element and consists of colorless crystals of rather strong refractive power, but of weak double refraction. By this he means that alit in polarized light between crossed nicol prisms has insufficient optical activity to produce more than weak bluish gray interference colors.

"Celit is recognized by its deep color, brownish orange. It fills the interstices between the other constituents, being the magma or liquid of lowest freezing-point out of which the alit is separated. It is strongly double refractive, that is to say, gives brilliant colors when examined between crossed nicol prisms.

"Belit is recognized by its dirty green and somewhat muddy color and by its brilliant interference colors. It is biaxial and of high index of refraction. It forms small round grains of no recognized crystalline character.

"Felit is colorless. Its index of refraction is nearly the same as that of belit and it is strongly double refractive. It occurs in the form of round grains, often in elongated form, but without crystalline outline. Felit may be entirely wanting.

"Besides these minerals an amorphous isotropic mass was detected by Törnebohm and Le Chatelier. It has a very high refractive index.

"Törnebohm adds the important fact that a cement 4 per cent richer in lime than usual consists almost entirely of alit and celit."

Theories of constitution.—Until recently Portland-cement clinker was commonly assumed to be a mixture of two or more definite chemical compounds, and the principal points at issue between various investigators were: (1) the exact formulas for these compounds, and (2) the proportion in which they must exist to give a good Portland cement. The two theories, in this regard, that have made the most impression upon modern cement practice are those presented respectively by Le Chatelier and Newberry. Recently, however, Richardson has formulated a theory of entirely different type. These three explanations of the constitution of Portland clinker will, therefore, be described briefly.

Le Chatelier, speaking of Portland-cement clinkers, states * that:

"Examined in thin plates under the microscope they are formed of tricalcic silicate in crystals, with very feeble double refraction, embedded in a crystalline ground-mass of silico-alumina—ferrites of lime. These are the two essential elements of Portland cement. If the lime is in excess, aluminate of lime is first formed; then for a still greater excess, ferrite of lime, and finally free lime. If, on the other hand, the lime is deficient in quantity, a dicalcic silicate is formed, recognizable by the spontaneous crumbling of the burnt pieces of cement. When the mixture is imperfect or the burning insufficient, the reactions remain incomplete, and although the average composition may be suitable, there is a simultaneous production of free lime and aluminate of calcium with dicalcic silicate. In a Portland cement of normal composition the proportion of lime, according to the chemical formulas of the compound, should be greater than that determined by the following formula:

$$\frac{SiO_2 - Al_2O_3 - Fe_2O_3}{CaO} > 3, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

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* Trans. Amer. Inst. Mining Engineers, vol. 22, pp. 3-52.

in which CaO, SiO_2, Al_2O_3, Fe_2O_3 represent not the equivalent weights but the number of equivalents of these substances present; that is to say, the quotients of the weights of the substances divided by their equivalent weights.* This proportion of lime must never, on the other hand, reach the relation indicated by the following formula:

$$\frac{CaO}{SiO_2+Al_2O_3-Fe_2O_3}<3, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

which corresponds to the exclusive formation of aluminate of calcium. It is necessary, by reason of the inevitable imperfection of the mixture, to keep always well below this limit, beyond which there will remain uncombined lime. In the use of this formula, magnesia should be added to the lime and sulphuric acid to the denominator after dividing its number of equivalents by 3."

On a later page Le Chatelier states that Portland cements of good quality would give a value between 3.5 and 4.0 for formula 1, and between 2.5 and 2.7 for formula 2.

The Newberrys, working on synthetic cements prepared from pure raw materials, obtained results differing from those of Le Chatelier in one important particular. They agreed with him that the lime and silica combined in the form of the tricalcic silicate $3CaO.SiO_2$; but in regard to the lime-alumina compound they decided that it was present as the dicalcic aluminate $2CaO.Al_2O_3$ instead of in the tricalcic form given by Le Chatelier. These results gave, as the general formula for a pure Portland,

$$x(3CaO.SiO_2)+y(2CaO.Al_2O_3).$$

No allowance is made for magnesia, as the experimenters decided that it could not give a hydraulic product if present in Portland cement; while iron is neglected because of the small percentage in which it usually occurs.

Richardson, working both with the microscope and with synthetic preparations, has evolved a theory of much ingenuity and complexity by treating the investigation as a study in solid solutions. For the details of this remarkable and important work reference should be made to his original papers.† In the present place only a brief summary of his principal conclusions can be given.

He believes that the two principal constituents of a good Portland-

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* For a table of combining weights, see p. 11 of this volume.

† See list on p. 575.

cement clinker are the materials identified under the microscope by Törnebohm and named alit and celit; that alit is a solid solution of tricalcic aluminate ($3CaO.Al_2O_3$) in tricalcic silicate ($CaO.SiO_2$), while celit is a solid solution of dicalcic aluminate ($2CaO.Al_2O_3$) in dicalcic silicate ($2CaO.SiO_2$).

"Having determined that alit and celit are solid solutions of aluminates in silicates, the aluminates being present in less than an amount sufficient to make a saturated solution of aluminate in the silicate, it becomes of interest to consider how these solutions are formed during the conversion of a raw mixture or of a mixture of pure chemicals into a clinker. It would be simple to understand this if fusion took place in its formation, but this does not happen, the material is only sintered. If two gases are brought together they diffuse into each other with very great rapidity. If two liquids are poured one upon the other in layers without mixing, they diffuse more slowly. If solids are brought into contact it would be naturally assumed that diffusion would cease. Experiments of Robert-Austen have shown that molecular mobility in solids exists, since when carefully polished surfaces of gold and lead are brought into contact and left under pressure for some months, at the ordinary temperatures, gold is diffused into the lead and the lead into the gold for an appreciable distance. Mixtures of the components which would produce a fusible wood metal when subjected to pressure at ordinary temperature become converted into this alloy. Anhydrous sulphate of soda and carbonate of barium also diffuse when brought into close contact with the formation of barium sulphate and carbonate of soda. It is not difficult to understand, therefore, how at a temperature of 1650° C. the particles of silica, alumina, and lime may diffuse below the melting-point of the resulting clinker to form a Portland cement, and the fact that such a clinker is stable depends not only on its composition, but upon the fact that the diffusion has been complete, even in material which is only sintered. Sintering, therefore, may be defined as diffusion at a temperature below the melting-point of the components or of the resulting solid solution. That diffusion under such conditions is surprisingly rapid is seen by placing a particle of ferric oxide on the surface of white Portland-cement clinker, and then submitting it to a moderately high temperature. The rapid diffusion of iron through the white clinker can readily be noticed by the color which spreads through the mass. It is evident that the higher the temperature the more rapid the diffusion until it becomes very rapid on fusion. From this it may be concluded that the length of time during which it is necessary to expose any mixture of silica alumina and lime to a temperature is a function of the temperature, and should be longer, the lower the temperature."

Setting properties of Portland cement.—The theory which has been quite generally accepted as explaining the setting of Portland cement was that advanced by Le Chatelier. He considered that the aluminate of lime, in contact with water, hydrated and hardened like plaster, according to the equation:

$$3CaO.Al_2O_3+12H_2O=3CaO.Al_2O_3.12H_2O.$$

To this action of the aluminate was ascribed the initial set of the cement. The later hardening was ascribed, however, to the decomposition of the lime silicate. In contact with water it sets, dividing so as to give hydrated monocalcic silicate crystallizing in microscopic needles, and calcium hydrate crystallizing in large hexagonal plates:

$$3CaO.SiO_2+\text{water}=CaO.SiO_2.2\tfrac{1}{2}H_2O+2(CaO.H_2O).$$

In general this theory, has been accepted.

Richardson, however, has recently modified* this theory in an important way. He considers that the setting of Portland cement is due to the decomposition of the silicates and aluminates of the clinker by the action of water, producing lime hydrate ($Ca_2H_2O_2$) in a peculiarly active form.

"On the addition of water to a stable system made up of the solid solutions which composed Portland cement a new component is introduced which immediately results in a lack of equilibrium, which is only brought about again by the liberation of free lime. This free lime the moment that it is liberated is in solution in the water, but owing to the rapidity with which it is liberated from the aluminate, the water soon becomes supersaturated with calcic hydrate, and the latter crystallizes out in a network of crystals which binds the particles of undecomposed Portland cement together. From the characteristics of the silicates and aluminates it is evident that the latter are acted upon much more rapidly than the silicates, and it is to the crystallization of the lime from the aluminates that the first or initial set must be attributed. Subsequent hardening is due to the slower liberation of lime from the silicates. If the lime is liberated more rapidly than is possible for it to crystallize out from the water, expansion ensues and the cement is not volume constant."

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* Richardson C. The setting or hydration of Portland cement. Engineering News, vol. 53, pp. 84–85. Jan. 26, 1905.

He further notes that of the two constituents of the clinker the celit is almost inert, being usually unattacked by the water, while the alit furnishes most of the lime needed for the setting effect. As the celit is a solution of dicalcic salts ($2CaO.SiO_2+2CaO.Al_2O_3$), while the alit is a solution of tricalcic compounds ($3CaO.SiO_2+3CaO.Al_2O_3$), the lower-limed cements are, therefore, the less hydraulic. This agrees with experience.

This theory differs from Le Chatelier's in that it considers setting as due only indirectly to the presence of silicates and aluminates.

"The strength of the Portland cement after setting is due entirely to the crystallization of calcium hydrate under certain favorable conditions, and not at all to the hydration of the silicates or the aluminates, since in this act of hydration nothing can take place which would tend to bind these silicates and aluminates together."

The formation of lime silicates and aluminates during clinkering is on this theory only a convenient way of securing indirectly a very active lime hydrate, which is itself the real cementing material.

Replacement of silica by other acids.—Various oxides of the silica group have been substituted by Richardson in his series of synthetic cements. Titanic oxide (TiO_2), stannic oxide (SnO_2), and plumbic oxide (PbO) have been so used. "The ground clinker in each case has been found to set rapidly, although the resulting test pieces were not volume constant, the temperature obtainable in our furnace being evidently insufficient to bring about a thorough combination between these oxides and lime. Cements have been made in which phosphoric acid (P_2O_5) has been substituted for silica."

Replacement of alumina by iron oxide.—Some difference of opinion appears concerning the extent to which the alumina of a Portland cement may be replaced by iron oxide.

This problem was taken up by the Newberrys in the classic researches before cited. They prepared mixtures of pure iron oxide and calcium carbonate in such proportions as to correspond to the formula $2CaO.Fe_2O_3$, which in percentages is equivalent to CaO 41.3 per cent, Fe_2O_3 58.7 per cent. "On burning, the material fused to a black slag, which yielded a brown color on grinding. Mixed with water to a paste, this powder showed no heating, and did not set or harden in air or cold water. A part placed in steam however, after setting one day in air, hardened rapidly, and after several hours in boiling water showed no cracking and appeared very hard. From this experiment it appears that lime and iron oxide readily combine, yielding a product which is constant in volume, though it shows no hardening properties in the cold." The

Newberrys carry the experiments further, making a silica-, iron oxide, lime mixture entirely free from alumina. This was made to correspond to the formula

$$(3CaO.SiO_2) + \times (2CaO.Fe_2O_3),$$

and contained about 7 per cent of iron oxide. On burning this gave a black, fusible clinker. When powdered this was dark-gray, and gave a slow-setting hard and sound cement.

Their final conclusions were, that though "iron oxide evidently combines with lime in the same manner as alumina," the amount of iron oxide present in ordinary clays is so small that "it is quite unnecessary, in working with ordinary clays, to take the iron oxide into consideration in calculating the amount of lime required."

In view of the manufacture of cements containing appreciable percentages of iron oxide, it seems advisable to take this constituent into consideration in proportioning mixes, and this has accordingly been done in the formula given earlier in this volume.

Replacement of lime by magnesia.—The possibility of this replacement has been flatly denied by some of our leading authorities on cement chemistry, while it has been maintained, but less confidently, by others. To the present writer it seems certain that magnesia is absolutely interchangeable with lime, due regard being paid to their differences in atomic weight. It is only necessary to adduce the example of the high-burned natural cements, such as the Akron, to make it clear that a cement containing 15 to 20 per cent of magnesia can be made at almost clinkering temperature. Recent experiments by Newberry seem to confirm this conclusion. It is to be noted, however, that a Portland cement carrying high percentages of magnesia will necessarily differ considerably from our present-day lime Portlands. It is even probable that the differences in physical and technical properties will be so great that it will be necessary to market such magnesia Portlands under some distinct trade-name.

Replacement of lime by other bases.—Magnesia is not the only base that can replace, either partly or entirely, the lime of a normal Portland-cement clinker. Other alkaline earths can be so substituted, as was proven in the course of Richardson's recent experiments. He describes * this phase of his work as follows:

"Clinkers have been made in which baryta (BaO) and strontia (SrO) are the bases. They must be burned at a very much higher temperature than similar clinkers containing lime. In powder these

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* Engineering News, vol. 53, p. 85. Jan. 26, 1905.

(barium and strontium cements) possess strong hydraulic properties, and are volume constant in water for a few days, but owing to the greater solubility in water of barium and strontium hydrate than of lime hydrate, the material after setting is much more readily attacked by water than is lime cement, strontium hydrate being about twice as soluble as calcium hydrate, and barium hydrate about eight times as soluble."

References on the constitution of Portland cement.—The following brief list will serve as an introduction to the mass of literature on this subject:

Bonnami, H. Fabrication et controle des chaux hydrauliques et des ciments. 8vo, 276 pp. Paris, 1888.

Le Chatelier, H. Tests of hydraulic materials. Trans. Amer. Inst. Mining Engineers, vol. 22, pp. 3–52. 1894.

Newberry, S. B. and W. B. The constitution of hydraulic cements. Journ. Soc. Chem Industry, vol. 16, pp. 887–894. 1897

Richardson, C. The constitution of Portland cement. Cement, vols. 3, 4, 5. 1903–1905

Richardson, C. The constitution of Portland cement from a physico-chemical standpoint. 12mo, 20 pp. Long Island City, N. Y., 1904.

Richardson, C. The setting or hydration of Portland cement. Engineering News, vol. 53, pp. 84–85. Jan. 26, 1905.

Composition of Portland cements.—The chemical composition of Portland cements has been changing slowly in one direction since 1850. This is well brought out by the analyses of old Portland cements given in the following table, when compared with the analyses of modern Portlands given in Table 221.

TABLE 220.

ANALYSES OF PORTLAND CEMENT, 1849–1873.

	1.	2.	3.	4.
Silica (SiO_2)	18.60	22.23	23.72	18.60
Alumina (Al_2O_3)	11.30	7.75	7.36	4.75
Iron oxide (Fe_2O_3)	17.90	5.30	5.05	5.60
Lime (CaO)	49.80	54.11	54.40	58.50
Magnesia (MgO)	0.70	0.75	0.86	2.55
Alkalies (K_2O,Na_2O)	n. d.	1.76	2.62	1.70
Sulphur trioxide (SO_3)	n. d.	1.00	1.12	2.10
Carbon dioxide (CO_2)	n. d.	2.15	2.80	0.50
Water	n. d.	1.00	0.96	0.50

1. Manufactured about 1873 by I. C. Johnson & Co., England. Reports Vienna Exposition, vol. 4, pt. D, p. 35.
2. Manufactured about 1849 in England. Analyzed by Pettenkofer. Proc. Institution Civil Engineers, vol. 62, p. 77.
3. Manufactured about 1873 in England. Analyzed by Feichtinger. Reports Vienna Exposition, vol. 4, pt. D, p. 37.
4. Manufactured about 1873 in Austria. Analyzed by Wagner. Reports Vienna Exposition, vol. 4, pt. D, p. 37.

From inspection of the above table it will be seen that old Portlands were very low-limed products. Some, in fact, were too low in lime to be considered, at the present day, as falling in the Portland class.

Composition of American Portland cements.—Table 221, containing a large series of analyses of American Portland cements, has been compiled by the writer from various sources. About half of the analyses contained in it have already been published in different books and periodicals, while for the remainder the writer is indebted to the chemists of the various plants.

Standard Methods of Analysis.

The following methods of analysis are those suggested by a committee of the New York section, Society of Chemical Industry, consisting of W. F. Hillebrand and Clifford Richardson. For exact work it is desirable that these methods be closely followed. They are not intended for use in making the rapid determinations which are necessary for the control of the mix when the plant is in operation. A method of rapid analysis has recently been published by several members of the Lehigh section, American Chemical Society, which is probably well adapted for use in the Lehigh cement district; but it is doubtful if it is worth while attempting to formulate standard methods for rapid analysis, since the requirements vary so much at the different plants.

Method Suggested for the Analysis of Limestones, Raw Mixtures and Portland Cements.*

Solution.—One-half gram of the finely powdered substance is to be weighed out and, if a limestone or unburned mixture, strongly ignited in a covered platinum crucible over a strong blast for fifteen minutes, or longer if the blast is not powerful enough to affect complete conversion to a cement in this time. It is then transferred to an evaporating dish, preferably of platinum for the sake of celerity in evaporation, moistened with enough water to prevent lumping, and 5 to 10 c.c. of strong HCl added and digested, with the aid of gentle heat and agitation until solution is completed. Solution may be aided by light pressure with the flattened end of a glass rod.† The solution is then evaporated to dryness, as far as this may be possible on the steam-bath.

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* Eng. News, 50, p. 60. Eng. Record, 48, p. 49. Cement, Sept., 1903.

† If anything remains undecomposed it should be separated, fused with a little Na_2CO_3, dissolved and added to the original solution. Of course, a small amount of the separated non-gelatinous silica is not to be mistaken for undecomposed matter.

TABLE 221.

ANALYSES OF AMERICAN PORTLAND CEMENTS.

State.	Brand.	Company.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alk.	SO_3
Alabama	Red Diamond	Alabama P. C. Co.	19.56	12.16		62.27	0.64	......	0.54
"	" "	" "	19.91	13.63		63.82	0.83	......	1.16
"	" "	" "	20.25	13.44		63.60	1.03	......	0.41
"	" "	" "	19.99	13.74		61.36	0.61		
"	" "	" "	20.54	8.55	3.84	63.85	0.66		
Arkansas	Setter	Whitecliffs P. C. Co.	22.93	10.33		64.67	0.94	......	1.05
California	Golden Gate	Pacific P. C. Co.	22.57	10.64		62.61	1.27	......	1.32
"	" "	" "	22.40	10.76		63.10	1.22	......	1.15
"	" "	" "	22.44	10.52		63.05	1.51	......	0.78
"	" "	" "	22.25	7.65	3.35	62.85	0.78	0.69	1.34
"	Colton	California P. C. Co.	21.1	12.9		63.5	0.7	......	1.6
"	Santa Cruz	" "	23.48	8.47	5.18	61.91	n. d.	0.92	n. d.
Colorado	Ideal	Colorado P. C. Co.	21.60	8.04	2.82	64.35	1.08	......	1.47
Illinois	Owl	German-American P. C. Co.	24.12	9.78		61.45	2.56	......	1.23
"	"	" " "	23.09	5.13	3.52	64.36	2.43	......	1.53
Indiana	South Bend	Millens P. C. Works	22.30	7.21	3.79	59.24	3.03	......	1.47
"	Wabash	Wabash P. C. Co.	21.78	7.31	2.65	62.35	2.88	0.47	1.78
"	Sandusky	Sandusky P. C. Co.	22.06	4.80	1.66	65.44	2.82	......	0.90
Missouri	Red Ring	St. Louis P. C. Co.	22.50	6.20	2.50	64.80	0.75	......	1.15
Michigan	Wyandotte	Michigan Alkali Co.	22.50	10.90		60.95	1.32	0.68	2.50
"	"	" " "	24.00	7.50	2.40	62.00	2.50	......	1.50
"	Wolverine	Michigan P. C. Co.	21.02	7.51	3.83	63.95	1.05	0.98	1.50
"	Alpena	Alpena P. C. Co	20.26	8.62	2.71	63.22	2.34	1.34	0.76
"	Bronson	Bronson P. C. Co.	20.95	9.74	3.12	63.17	0.75	......	0.86
"	Peerless	Peerless P. C. Co.	20.65	11.08		65.40	1.95	......	0.37
"	Peninsular	Peninsular P. C. Co.	22.56	10.96		62.72	2.20	......	1.50
"	Omega	Omega P. C. Co.	24.24	7.26	2.54	64.96	2.26	......	0.41
New Jersey	Alpha	Alpha P. C. Co.	20.54	10.54		62.92	2.73	......	1.21
" "	"	" "	21.70	8.88		63.27	0.55		
" "	"	" "	22.62	8.76	2.66	61.46	2.92	......	1.52
" "	"	" "	22.89	8.00	2.44	63.38	2.30		

TABLE 221—(*Continued*).

ANALYSES OF AMERICAN PORTLAND CEMENTS.

State.	Brand.	Company.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alk.	SO_3
New Jersey	Edison	Edison P. C. Co.	20.14	7.51	3.33	62.71	2.34		1.64
" "	Vulcanite	Vulcanite P. C. Co.	21.08	7.86	2.48	63.68	2.62		1.25
New York	Catskill	Catskill P. C. Co.	22.48	6.52	4.46	62.93	1.48		1.30
" "	"	" "	21.94	6.02	4.38	64.62	1.25		1.12
" "	"	" "	23.44	6.35	3.99	63.21	1.15		1.22
" "	Empire	Empire P. C. Co.	20.80	7.39	2.61	64.00	n. d.		n. d.
" "	"	" "	22.04	6.45	3.41	60.92	3.53		2.73
" "	"	" "	21.98	8.20	3.70	61.83	1.43	0.84	1.18
" "	Iron Clad	Glens Falls P. C. Co.	21.50	10.50		63.50 61.78	1.80 1.27	0.40	1.50 1.53
" "	Hudson	Hudson P. C. Co.	21.60	9.27	3.80				
" "	Jordan	American C. Co.	21.86	7.17	3.73	61.14	2.34		1.94
" "	Millen's	Wayland C. Co.	21.08	9.56		64.68	1.85	0.90	1.93
" "	"	" "	22.19	9.72		63.08	2.04	1.22	1.75
Ohio	Alma	Alma P. C. Co.	21.63	6.70	4.75	63.58	1.10		1.15
"	Buckeye	Buckeye P. C. Co.	21.20	6.05	3.33	58.07	2.80	2.20	
"	"	" "	20.75	13.50		62.25	0.25	2.25	0.25
"	Diamond	Diamond P. C. Co.	21.80	7.95	4.95	61.90	1.64		0.79
"	"	" "	22.31	6.97	4.28	63.10	0.38	1.31	0.84
"	Ironton	Ironton P. C. Co.	21.04	11.78		63.80	n. d.		1.38
Pennsylvania	Atlas	Atlas P. C. Co.	21.96	8.29	2.67	60.52	3.43		1.49
"	"	" "	21.30	7.65	2.85	60.95	2.95	1.15	1.81
"	Dragon	Lawrence P. C. Co.	20.87	7.60	2.66	63.04	2.80		1.50
"	Giant	American C. Co.	23.26	8.07	4.83	59.28	1.00	0.50	0.50
"	"	" "	20.99	4.12	5.18	60.75	0.41		1.40
"	"	" "	19.92	9.83	2.63	60.32	3.12		1.13
"	"	" "	22.08	8.52	4.81	62.12	1.71		
"	"	" "	22.45	13.23		61.37	0.66	0.71	1.37
"	"	" "	22.90	12.10		60.13			
"	Lehigh	Lehigh P. C. Co.	21.04	10.46		62.46	2.56		1.56
"	"	" "	22.61	9.55		62.45	2.61		1.45
"	"	" "	22.29	9.48		62.54	2.49		1.51

TABLE 221—(*Continued*).

ANALYSES OF AMERICAN PORTLAND CEMENTS.

State.	Brand.	Company.	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alk.	SO_3
Pennsylvania. . . .	Lehigh.	Lehigh P. C. Co.	22.13	9.56		62.63	2.51	. . . . . .	1.49
" . . .	"	" "	22.00	9.74		62.34	2.54	. . . . . .	1.40
" . . .	"	" "	22.19	10.18		62.39	2.62	. . . . . .	1.53
" . . .	"	" "	22.26	9.49		62.46	2.65	. . . . . .	1.56
" . . .	Nazareth.	Nazareth P. C. Co.	19.06	7.47	2.29	61.23	2.83	1.41	1.34
" . . .	Phœnix.	Phœnix P. C. Co.	21.65	8.09	2.93	63.10	2.00	. . . . . .	1.02
" . . .	Northampton	Northampton P. C. Co.	21.18	7.03	2.41	63.06	2.05		
" . . .	Reading.	Reading C. Co.	24.23	4.80	1.86	63.01	3.20	. . . . . .	1.20
" . . .	"	" "	24.48	4.51	2.68	64.33	2.59	. . . . . .	1.41
" . . .	Saylors.	Saylors P. C. Co.	22.04	10.11	1.61	62.93	1.13	. . . . . .	1.78
" . . .	"	" "	22.68	6.71	2.35	62.30	3.41	. . . . . .	1.88
" . . .	"	" "	21.25	8.25	4.21	61.25	1.50	2.00	1.38
South Dakota. . . .	Yankton.	Western P. C. Co.	22.00	7.74	4.61	59.50	0.90	1.20	0.80
" " . . .	"	" "	21.80	11.86		60.00	0.80	1.80	2.86
Texas.	Live Oak.	Texas P. C. Co	22.50	8.35	4.25	62.35	. . . . . .	. . . . . .	1.75
Virginia.	Old Dominion.	Virginia P. C. Co.	21.20	7.90	2.82	63.14	2.40	. . . . . .	1.37
"	" "	" "	22.01	8.40	3.07	63.68	1.52	. . . . . .	0.54
"	" "	" "	20.65	6.93	2.76	63.47	2.76	. . . . . .	1.34

Silica.—The residue, without further heating, is treated at first with 5 to 10 c.c. of strong HCl, which is then diluted to half strength or less, or upon the residue may be poured at once a larger volume of acid of half strength. The dish is then covered and digestion allowed to go on for ten minutes on the bath, after which the solution is filtered and the separated silica washed thoroughly with water. The filtrate is again evaporated to dryness, the residue, without further heating, taken up with acid and water, and the small amount of silica it contains separated on another filter-paper. The papers containing the residue are transferred wet to a weighed platinum crucible, dried, ignited, first over a Bunsen burner until the carbon of the filter is completely consumed, and finally over the blast for fifteen minutes and checked by a further blasting for ten minutes or to constant weight. The silica, if great accuracy is desired, is treated in the crucible with about 10 c.c. of HFl and four drops of H_2SO_4 and evaporated over a low flame to complete dryness. The small residue is finally blasted for a minute or two, cooled, and weighed. The difference between this weight and the weight previously obtained gives the amount of silica.*

Al_2O_3 and Fe_2O_3: The filtrate, about 250 c.c. from the second evaporation for SiO_2, is made alkaline with NH_4OH after adding HCl, if need be, to insure a total of 10 to 15 c.c. strong acid, and boiled to expel excess of NH_3, or until there is but a faint odor of it, and the precipitated iron and aluminum hydrates, after settling, are washed once by decantation and slightly on the filter. Setting aside the filtrate, the precipitate is dissolved in hot dilute HCl, the solution passing into the beaker in which the precipitation was made. The aluminum and iron are then precipitated by NH_4OH, boiled and the second precipitate collected and washed on the same filter used in the first instant. The filter-paper, with the precipitate, is then placed in a weighed platinum crucible, the paper burned off and the precipitate ignited and finally blasted 5 minutes, with care to prevent reduction, cooled and weighed as $Al_2O_3+Fe_2O_3$.†

Fe_2O_3: The combined iron and aluminum oxides are fused in a platinum crucible at a very low temperature with about 3 to 4 grams of $KHSO_4$, or, better, $NaHSO_4$, the melt taken up with so much dilute H_2SO_4 that there shall be no less than 5 grams absolute acid and enough water to effect solution on heating. The solution is then evaporated and eventually heated till acid fumes come off copiously. After cooling

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* For ordinary control work in the plant laboratory this correction may, perhaps, be neglected; the double evaporation never.

† This precipitate contains TiO_2, P_2O_5, Mn_3O_4.

and redissolving in water the small amount of silica is filtered out, weighed, and corrected by HFl and H_2SO_4.* The filtrate is reduced by zinc, or preferably by hydrogen sulphide, boiling out the excess of the latter afterward while passing CO_2 through the flask, and tritrated with permanganate.† The strength of the permanganate solution should not be greater than .0040 grains Fe_2O_3 per c.c.

CaO: To the combined filtrate from the $Al_2O_3 + Fe_2O_3$ precipitate a few drops of NH_4OH are added, and the solution brought to boiling. To the boiling solution 20 c.c. of a saturated solution of ammonium oxalate is added, and the boiling continued until the precipitated CaC_2O_4 assumes a well-defined granular form. It is then allowed to stand for 20 minutes, or until the precipitate has settled, and then filtered and washed. The precipitate and filter are placed wet in a platinum crucible, and the paper burned off over a small flame of a Bunsen burner. It is then ignited, redissolved in HCl, and the solution made up to 100 c.c. with water. Ammonia is added in slight excess, and the liquid is boiled. If a small amount of Al_2O_3 separates, this is filtered out, weighed, and the amount added to that found in the first determination, when greater accuracy is desired. The lime is then reprecipitated by ammonium oxalate, allowed to stand until settled, filtered, and washed,‡ weighed as oxide by ignition and blasting in a covered crucible to constant weight, or determined with dilute standard permanganate.§

MgO: The combined filtrates from the calcium precipitates are acidified with HCl, and concentrated on the steam-bath to about 150 c.c., 10 c.c. of saturated solution of $Na(NH_4)HPO_4$ are added, and the solution boiled for several minutes. It is then removed from the flame and cooled by placing the beaker in ice-water. After cooling, NH_4OH is added drop by drop with constant stirring until the crystalline ummonium magnesium orthophosphate begins to form, and then in moderate excess, the stirring being continued for several minutes. It is then set aside for several hours in a cool atmosphere and filtered.

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* This correction of Al_2O_3, Fe_2O_3, for silica should not be made when the HFl correction of the main silica has been omitted, unless that silica was obtained by only one evaporation and filtration. After two evaporations and filtrations 1 to 2 mg. of SiO_2 are still to be found with the $Al_2O_3.Fe_2O_3$.

† In this way only is the influence of titanium to be avoided and a correct result obtained for iron.

‡ The volume of wash-water should not be too large, *vide* Hillebrand.

§ The accuracy of this method admits of criticism, but its convenience and rapidity demand its insertion.

The precipitate is redissolved in hot dilute HCl, the solution made up to about 100 c.c., 1 c.c. of a saturated solution of $Na(NH_4)HPO_4$ added, and ammonia drop by drop, with constant stirring until the precipitate is again formed as described and the ammonia is in moderate excess. It is then allowed to stand for about 2 hours when it is filtered on a paper or a Gooch crucible, ignited, cooled, and weighed as $Mg_2P_2O_7$.

K_2O and Na_2O: For the determination of the alkalies, the well-known method of Prof. J. Lawrence Smith is to be followed, either with or without the addition of $CaCO_3$ with $NHCl_4$.

SO_3: One gram of the substance is dissolved in 15 c.c. of HCl, filtered and residue washed thoroughly.*

The solution is made up to 250 c.c. in a beaker and boiled. To the boiling solution 10 c.c. of a saturated solution of $BaCL_2$ is added slowly, drop by drop, from a pipette and the boiling continued until the precipitate is well formed, or digestion on the steam-bath may be substituted for the boiling. It is then set aside overnight, or for a few hours, filtered, ignited, and weighed as $BaSO_4$.

Total sulphur.—One gram of the material is weighed out in a large platinum crucible and fused with Na_2CO_3 and a little KNO_3, being careful to avoid contamination from sulphur in the gases from source of heat. This may be done by fitting the crucible in a hole in an abestos board. The melt is treated in the crucible with boiling water and the liquid poured into a tall, narrow beaker, and more hot water added until the mass is disintegrated. The solution is then filtered. The filtrate contained in a No. 4 beaker is to be acidulated with HCl and made up to 250 c.c. with distilled water, boiled, the sulphur precipitated as $BaSO_4$ and allowed to stand overnight or for a few hours.

Loss on ignition.—Half a gram of cement is to be weighed out in a platinum crucible, placed in a hole in an asbestos board so that about three fifths of the crucible projects below, and blasted 15 minutes, preferably with an inclined flame. The loss by weight, which is checked by a second blasting of 5 minutes, is the loss on ignition.

Note.—Recent investigations have shown that large errors in results are often due to the use of impure distilled water and reagents. The analyst should, therefore, test his distilled water by evaporation and his reagents by appropriate tests before proceeding with his work.

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* Evaporation to dryness is unnecessary, unless gelatinous silica should have separated and should never be performed on a bath heated by gas, *vide* Hillebrand.

CHAPTER XXXIX.

PHYSICAL PROPERTIES: TESTING METHODS.

THE utilization of Portland cement does not properly come within the province of this volume, as it is already covered by several excellent books. An extensive and readily accessible literature has been created on the subject of testing methods and testing results; but most of this literature is more important to the professional cement-tester than to the cement-manufacturer or cement-user. In the present chapter the subject of testing will necessarily be considered, but merely incidentally. Stress will be laid, on the other hand, on the general properties which Portland cement develops in use, and attention will be directed to the chemical and physical agencies which operate to disintegrate, or weaken, or destroy the cement, or the structures in which it is used.

Physical Properties of Portland Cement.

Portland cement is at present used for many different purposes, and the use to which it is applied seems to be rapidly increasing. Under such circumstances it is necessary to supply a product well-fitted to withstand the various disintegrating agencies to which it may be subjected.

In its ordinary uses, in heavy masonry for example, the cement will be subjected to compressive stresses, but rarely to tensile. When used as a paving material it will encounter transverse stresses and severe abrasion. As a lining material its imperviousness will be tested. In other places, as in gun emplacements for example, it may be subjected to severe and often-repeated shocks.

To these physical agencies of disintegration or destruction, are added chemical agents, which are at times of paramount importance. Works exposed to sea-water, for example, are subject to purely chemical attack which must be guarded against so far as possible.

The situation might be summed up by stating that cement may fail through defects in its manufacture (internal agencies), or through the purely external agencies, and that these agencies may be either physical or chemical.

This brief outline will serve to give some idea of the wide scope which might be given to a discussion of the properties of Portland cement.

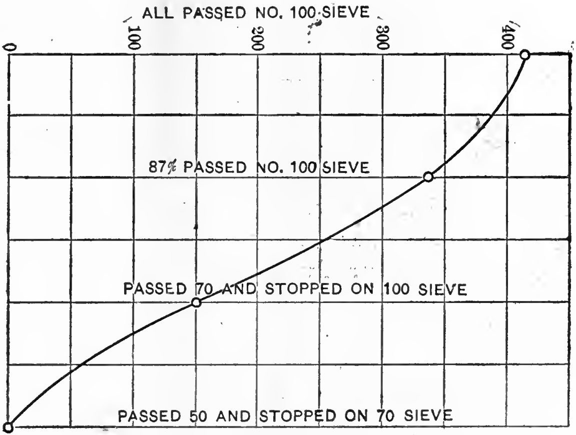

Fig. 143.*—Variation of tensile strength with fineness.

Value of fineness tests.—The reason for testing the fineness of a cement depends on the facts that (*a*) the strength of the cement, and particularly its tensile strength when mixed with sand, increases with the fineness, and (*b*) the soundness of the cement may be improved by fine grinding. The second point is one that concerns the manufacturer more than the user, because an unsound cement will usually fail to pass other tests and will therefore be rejected.

The increase in strength consequent on increased fineness is well shown in Figs. 143 and 144, both showing the results of tests on 1:3 mixtures, the tests of Fig. 143 having been made at four months while those in Fig. 144 are at various ages.

The value of fine grinding is evident, and engineers are constantly raising the standard of fineness in specifications. Unfortunately, however, they fail to make proper use of this fine cement after they have paid extra for getting it. They insist, for example, in obtaining cement which will pass 92 or 95 per cent through a 100-mesh sieve, and then use it in the same sand mixtures that they would if it were an English cement passing perhaps 85 per cent through 100-mesh.

The actual fineness of a number of typical American Portlands is shown very exactly in the tests given in Table 222.

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* From Johnson's "Materials of Construction", p. 409.

TABLE 222.

FINENESS OF VARIOUS AMERICAN PORTLANDS. (BLEININGER.)

Brand.	Reduced on.	Residue on 80-mesh Sieve.	Residue on 120-mesh Sieve.	Residue on 200-mesh Sieve.	Diameter between 0.008 and 0.002 Inches.	Diameter between 0.002 and 0.0002 Inches.	Diameter between 0.0003 and 0.0007 Inches.	Finer than Last Size.	Total Coarser than 200-mesh.
1	Tube mill.	7.07	14.56	4.45	22.08	19.29	7.36	24.69	25.98
2	" "	9.01	15.35	5.09	21.50	20.53	7.06	21.52	29.45
3	" "	12.12	15.05	7.61	21.11	16.85	5.91	21.37	34.78
4	" "	14.11	14.57	7.82	22.43	13.95	7.81	19.32	36.49
5	" "	3.84	17.64	5.10	25.27	12.56	10.16	20.42	26.58
6	Griffin mill.	3.06	15.41	8.24	28.56	16.48	12.74	15.51	26.72
7	" "	9.43	16.91	6.37	25.52	12.18	9.20	18.49	32.71
8	" "	5.00	15.42	14.52	27.30	19.10	9.22	14.88	29.53
9	" "	4.40	11.35	5.13	23.79	21.30	10.01	24.01	20.89
10	" "	4.18	13.30	5.07	22.63	14.64	12.31	28.79	22.55

Specific gravity.—The specific gravity of a Portland cement is a property which is of no importance of itself to the engineer. The reason for determining it is in order to rule out underburned or adulterated cement. The specific gravity of a well-dried sample of Portland cement will rarely fall below 3.10; while that of a natural cement, a slag cement, or a Portland adulterated with slag will rarely rise above

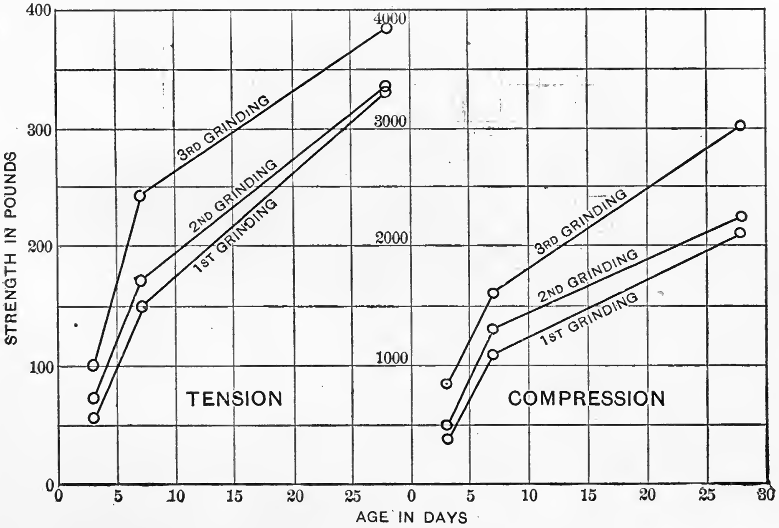

FIG. 144.*—Effect on strength of regrinding cement. (Tetmajer.)

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* From Johnson's "Materials of Construction", p. 411.

3.00. Some few American natural cements do, however, show a higher specific gravity, as can be seen from the table on page 263.

Setting properties.—A certain minimum time of initial and final set is usually specified, for the convenience of the workmen. This is regulated by the use of gypsum or plaster at the plant, a practice whose effects have been discussed in detail in Chapter XXXVI.

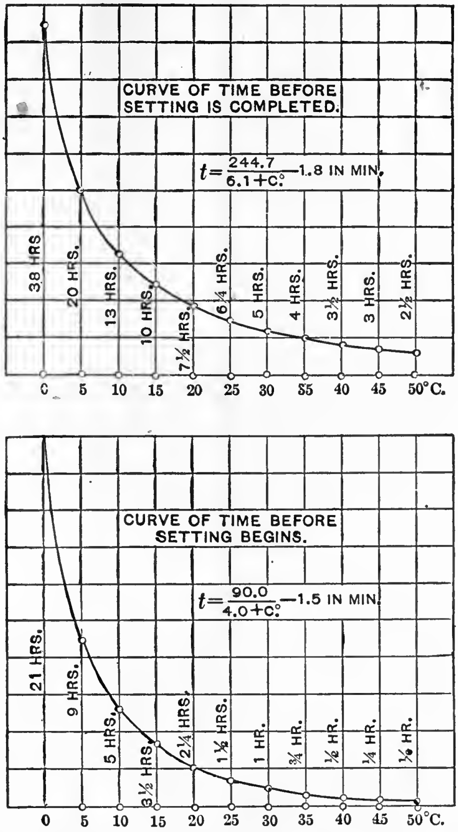

Fig. 145.*—Effect of temperature on setting time.

The effect of temperature on the setting of Portland cement is well shown in Fig. 145. It will be noted that the setting is much slower at low than at high temperatures, within the limits of the experiments.

Tensile strength.—The tensile strength of a cement is of very little importance or interest of itself, because cements are rarely subjected *intentionally* to tensile strains. But in practice the tensile test is the

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* From Johnson's "Materials of Construction," p, 616.

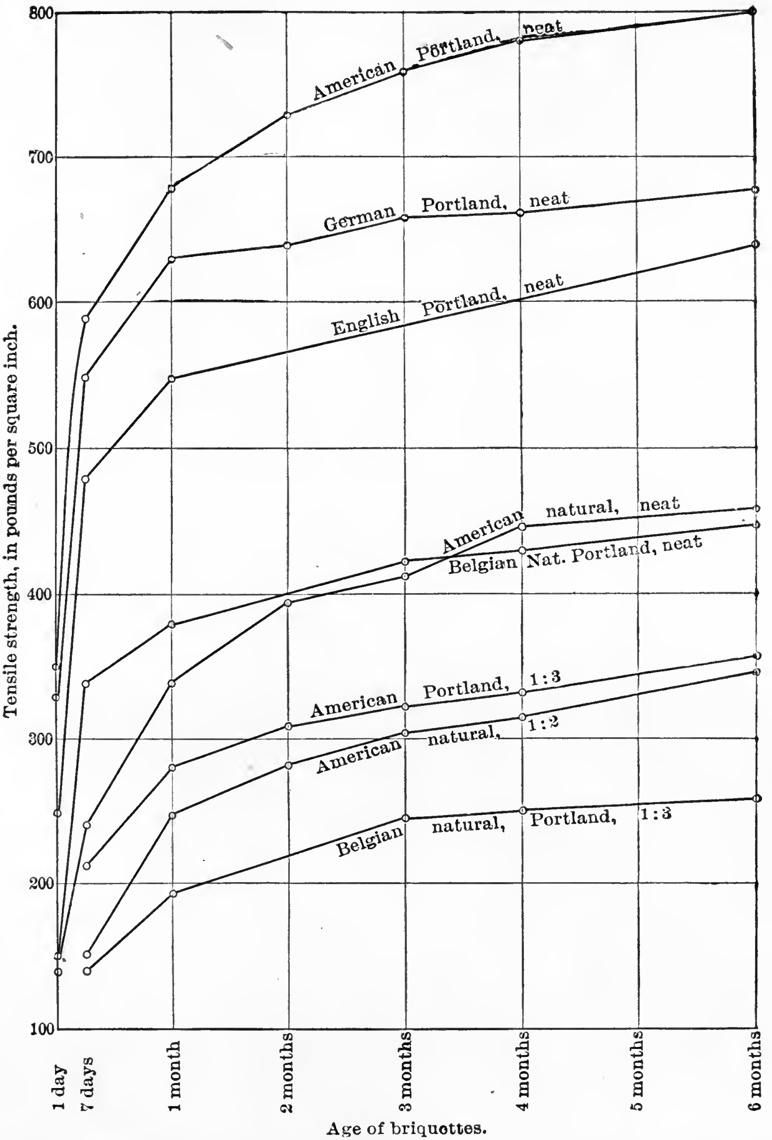

FIG. 146.—Tensile strength of various classes of cements. (Philadelphia tests, 1899.)

most commonly applied of all tests, this action being based on the assumption that the ratio between compressive and tensile strength for all Portland cements is quite uniform, and that therefore variations in tensile strength will indicate corresponding (though much greater) variations in compressive strength. This assumption is to a large extent correct, and for all practical purposes may be considered satisfactory. The question as to the ratio existing between the two types of strength will be taken up on a later page (p. 589.)

In Fig. 146 the results of a large series of tests on various classes of cement are shown diagrammatically. The cements tested included American and foreign Portlands, foreign "natural Portlands", and American natural cements, and the comparative results are quite representative.

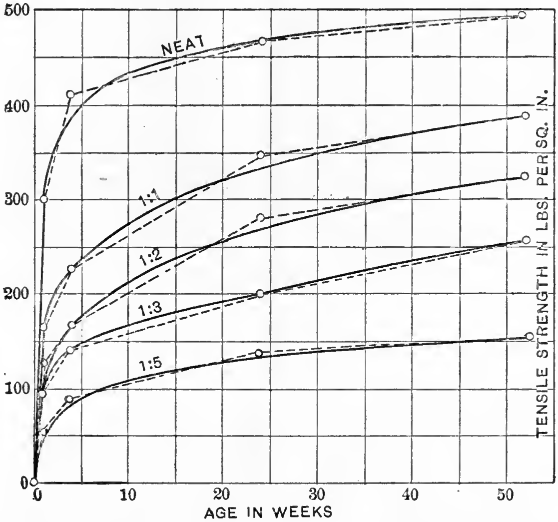

Fig. 147.*—Effect of proportions of sand on tensile strength.

The three points of most general interest in connection with tests of tensile strength are (*a*) the decrease in tensile strength with increase of percentage of sand, (*b*) the increase in strength with increased age, and (*c*) the variation in strength due to differences in the character of the sand. Two of these points are illustrated in Figs. 147 and 148, while all three are constantly discussed in engineering publications.

Compressive strength.—The compressive strength of a cement or concrete is a matter of direct practical importance, for these materials are rarely subjected to any other type of strain when used in actual

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* From Johnson's "Materials of Construction", p. 571.

work. Compressive tests, however, require the use of heavy testing machines, and are therefore not adapted for field or ordinary office tests. (See Tables 223 and 224.)

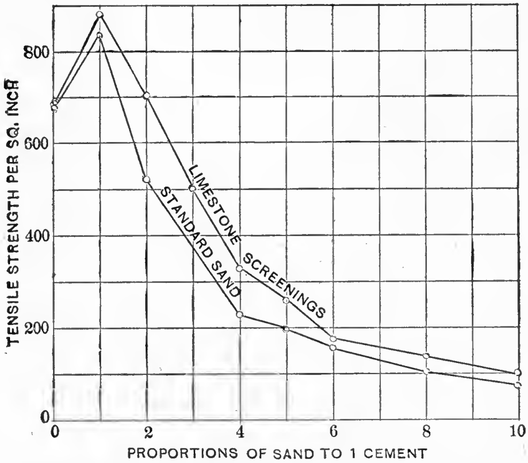

FIG. 148.*—Effect of character of sand on tensile strength.

TABLE 223.

COMPRESSIVE STRENGTH OF PORTLAND-CEMENT CUBES, WATERTOWN ARSENAL.

Brand.	Per Cent Water.	Compressive Strength, Pounds per Square Inch.		
		7 Days.	1 Month.	3 Months.
Alpha	25	6010	7340	8580
Atlas	25	3490	5370	5870
Lehigh	26.8	4280	5590	6310
"	18	5780	5990	6980
Star, with plaster	22.5	5960	7080	8170
" " "	25	6320	6750	8180
" " "	30	6340	6850	7720
" without plaster	22.5	4620	5180	5930
" " "	25	5560	5980	7730
" " "	30	5030	5620	6810
Whitehall	25	5630	6640	7630
Alsen	29.2	3510	4940	5510
Josson	26.7	2750	4030	4660

Report on Tests of Metals, etc., at Watertown Arsenal, 1902, pp. 369–376.

Ratio of compressive to tensile strength.—For a given age and mixture, the ratio between the compressive and tensile strength of a Portland-cement mortar is practically fixed. The ratio increases with increasing age, and also increases with increasing proportions of sand.

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* From Johnson's "Materials of Construction", p. 581.

In Fig. 149 are plotted the curves, by Johnson, resulting from comparison of a large series of tests by Tetmajer on 1:3 mixtures.

TABLE 224.

COMPRESSIVE STRENGTH OF PORTLAND-CEMENT MORTAR AND CONCRETE CUBES, WATERTOWN ARSENAL.

Brand.	Composition.			Age.			Size of Cube, Inches.	Compressive Strength per Square Inch.
	Cement.	Sand.	Stone.	Years.	Months.	Days.		
Atlas *......	1	1	..	2	5	20	6	11,330
" *......	1	1½	..	2	5	19	6	10,390
" *......	1	2	..	2	5	16	6	9,520
" *......	1	2½	..	2	5	17	6	8,110
" *......	1	3	..	2	5	15	6	6,140
" *......	1	3½	..	2	5	13	6	6,280
" *......	1	4	..	2	5	12	6	5,230
" *......	1	2	4	..	..	7	12	1,303
" *......	1	3	6	..	..	7	12	1,053
Alpha *.....	1	2	4	3	0	12	12	2,615
Vulcanite †..	1	2	4	..	1	22	12	3,392
" †..	1	2	4	..	2	25	12	4,135
Grant †.....	1	3	5	..	3	2	12	3,758

* Report on Tests of Metals, etc., at Watertown Arsenal, 1902, pp. 512–514.
† Ibid., 1900, pp. 1105–1111.

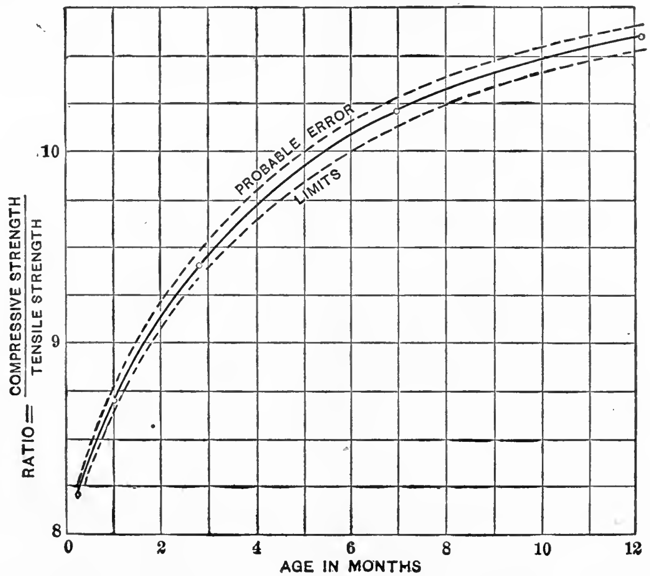

FIG. 149.‡—Ratio of compressive to tensile strength. (Johnson.)

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‡ From Johnson's "Materials of Construction", p. 419.

In practical use, it may be assumed that at the end of a year the average Portland-cement mortar will have a compressive strength about ten times as great as its tensile strength.

In Table 225 are given the results of a series of tests carried out at the Watertown Arsenal.* The tensile tests were made on the usual briquettes, the compressive tests on 2-inch cubes, and each average given is the result of ten tests. The cement used was the Peninsular brand, giving the following results for fineness and specific gravity.

Per cent of fineness:	
Retained on 98×100 sieve	4.95
Passed by 98×100 sieve; retained on 174×182 bolting-cloth	19.75
Passed by 174×182 bolting-cloth	75.30
Specific gravity:	
As taken from barrel	3.20
After mixing with 22 per cent water, setting 7 days in air, regrinding, and heating to a constant weight at 110° C	2.81

A chemical analysis of the cement is also given, but is evidently erroneous and therefore will not be quoted here.

TABLE 225.

RELATION OF TENSILE TO COMPRESSIVE STRENGTH. (WATERTOWN ARSENAL.)

Per Cent of Water.	Ages in		Tensile Strength, Pounds per Square Inch.			Compressive Strength, Pounds per Square Inch.		
	Air, Days.	Water, Days.	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
20	1	..	221	177	196	801	654	717
20	7	..	393	301	354	3430	2700	3040
20	28	..	641	487	566	4370	3490	3990
20	1	6	835	653	780	4830	3770	4250
20	1	27	952	857	906	8280	5730	7370
22	1	..	209	156	189	670	530	595
22	7	..	482	303	392	3680	3010	3260
22	28	..	518	421	457	4310	3030	3760
22	1	6	724	502	666	5370	3620	4720
22	1	27	1010	782	866	7810	5360	6870
25	1	..	223	148	190	450	398	430
25	7	..	475	301	402	3210	2120	2610
25	28	..	552	393	450	3550	2630	3130
25	1	6	388	251	329	4440	3360	3880
25	1	27	807	696	758	8740	6310	7580

Modulus of elasticity.—The determinations of the modulus of elasticity given in the following table were made at the Watertown Arsenal.

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* Report on Tests of Metals, etc., at Watertown Arsenal during 1902, p. 511. 1903.

TABLE 226.

Brand.	Composition.	Weight per Cubic Foot, Pounds.	Age. Mos.	Age. Dys.	Ultimate Strength, Pounds per Square Inch.	*E.*	Pounds per Square Inch.
Alpha.	Neat	135.5	1	. .	. . . .	*E*(500–2000) *E*(500–3000)	=3,000,000 =3,030,000
"	"	135.5	7	. .	8530	*E*(500–2000) *E*(2000–4000) *E*(4000–6000)	=3,488,000 =3,279,000 =2,963,000
"	"	137.3	1	. .	. . . .	*E*(500–2000)	=3,061,000
"	"	137.3	5	. .	9260	*E*(500–2000) *E*(2000–4000) *E*(4000–6000)	=4,545,000 =4,255,000 =3,846,000
Atlas.	"	134.7	2½	. .	. . . .	*E*(500–2000)	=2,326,000
"	"	134.7	6½	. .	5450	*E*(500–2000) *E*(2000–4000)	=2,479,000 =2,581,000
Lehigh. . . .	"	129.2	1	26	5800	*E*(500–2000) *E*(2000–4000)	=2,500,000 =2,353,000
"	1 cement:1 sand	133	1	26	3420	*E*(500–2000)	=2,778,000
"	Neat	135.9	1	26	7540	*E*(500–2000) *E*(2000–3000)	=4,348,000 =4,444,000
Peninsular.	"	135.3	2	13	6710	*E*(500–2000) *E*(2000–3000) *E*(3000–4000)	=3,571,000 =3,448,000 =3,125,000
"	"	138.0	2	14	6720	*E*(500–2000) *E*(2000–3000) *E*(3000–4000)	=3,846,000 =3,571,000 =3,509,000
"	1 cement:1 sand	133.4	2	13	4200	*E*(500–2000) *E*(2000–3000)	=2,941,000 =2,439,000

Sand cement.—Sand cement, or silica cement, is the name given to the product made by grinding up together Portland cement with an equal or greater quantity of sand, limestone, or other chemically inert substance. Description of the making and properties of sand cement is not properly part of a discussion of the manufacture of Portland cement, but rather a matter for the engineer to consider in connection with the uses of cement. For this reason the question will be touched on very briefly.

It is found that if Portland cement be mixed with an equal quantity of sand or limestone and the mixture ground very finely in a tube mill, the resulting product (sand cement) will show a strength almost or quite as great as the Portland cement from which it was made, notwithstanding the fact that the sand cement consists only half of Portland cement. When Portland cement is very expensive, economies are, therefore, possible in this line.

The gain in strength is due entirely to the extra fineness given by the extra grinding. The sand does not enter into chemical combination with the cement in any way, for ground limestone will give as good results as ground quartz.

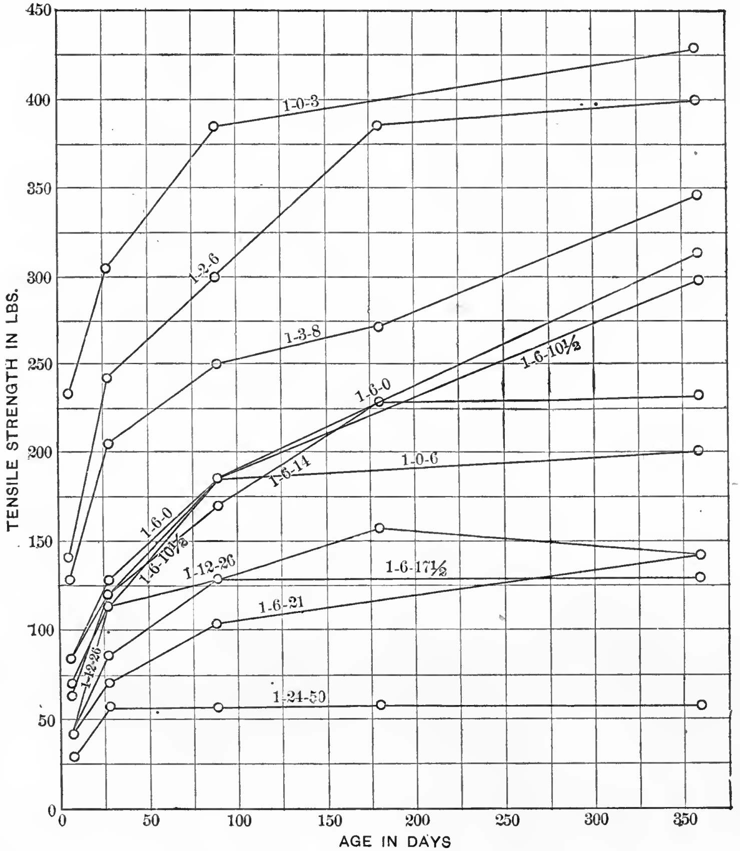

FIG. 150.*—Strength of sand-cement mortar. The first figure on each curve denotes parts of Portland cement; the second, parts of ground sand; the third, parts of unground sand.

The tests quoted in Table 227 were made at Albany in the laboratory of the State Engineer. Iron Clad is a Portland cement of high grade, while Victor is the sand cement made from it by grinding Iron Clad with limestone.

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* From Johnson's "Materials of Construction", p. 579.

TABLE 227.

COMPARATIVE TESTS OF PORTLAND CEMENT AND SAND CEMENT.

Cement.		Fineness.		Setting-time, Minutes.		Tensile Strength, Pounds.	
		50-Mesh.	100-Mesh	Initial.	Final.	7 Days.	28 Days.
1897.	Iron Clad, 1:3	100	94¾	51	122	170	274
	Victor, 1:3	100	96	35	79	198	265
1898.	Iron Clad, 1:3	99⅞	94¼	27	81	189	277
	Victor, 1:3	100	96	41	89	184	272
1899.	Iron Clad, 1:3	100	98	45	94	207	311
	Victor, 1:3	100	100	60	158	178	264

TABLE 228.

TENSILE AND COMPRESSIVE STRENGTH OF SAND CEMENTS. (SMITH.)

Name of brand	Citadel	Ensign	Jubilee
Sand cement composed of	1 cement 1 sand	1 cement 1 sand	1 cement 6 sand
Fineness: Passing 100-mesh	99.8	99.4	99.7
" 120- "	....	99.3	98.4
" 180- "	99.3		
Neat sand cement: Tension, 1 week	332		
" 4 weeks	475		
" 4 months	....	810	340
" 6 "	....	780	540
Compression, 4 weeks	3837		
Sand cement 1, sand 1: Tension, 1 week	....	....	300
" 2 weeks	....	....	379
Compression, 1 week	....	....	2800
Sand cement 1, sand 2: Tension, 1 week	....	....	184
" 2 weeks	....	....	215
Compression, 1 week	....	....	1225
Sand cement 1, sand 3: Tension, 1 week	135	189	
" 2 weeks	....	201	
" 4 "	141		
" 2 months	135		
Compression, 1 week	470	900	
" 4 weeks	687		

Brickbuilder, vol. 6, p. 281.

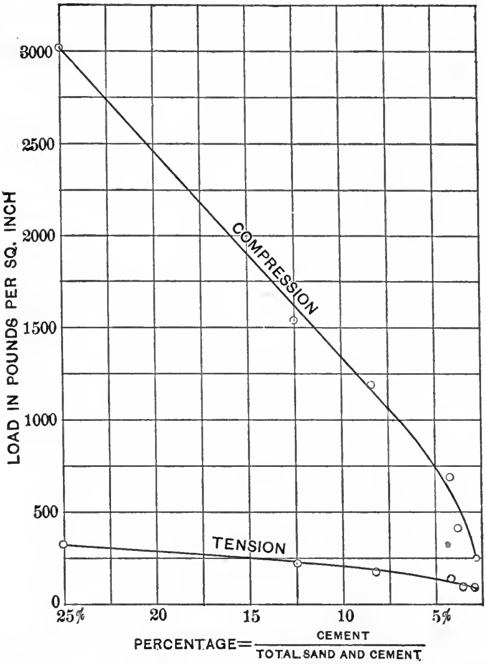

FIG. 151.*—Strength of sand-cement mortar with varying proportions of sand.

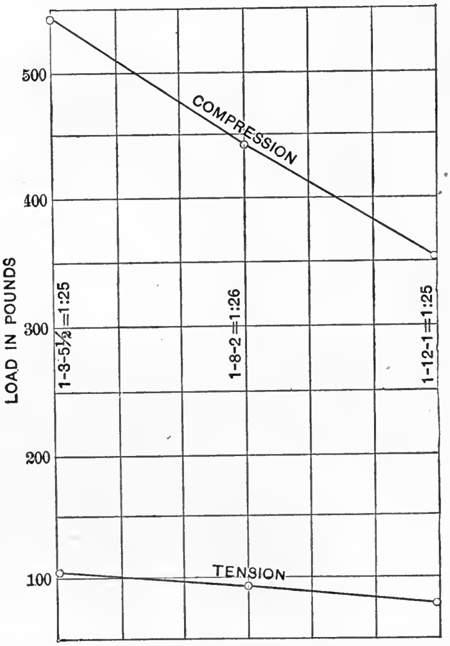

FIG. 152.†—Variation in strength of sand-cement mortar when the total proportion of sand is constant, but the relative proportions of ground and unground sand are variable.

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* From Johnson's "Materials of Construction", p. 580. † Ibid., p. 581

TABLE 229.

COMPRESSIVE STRENGTH OF SILICA-CEMENT CUBES. (WATERTOWN ARSENAL.)

Per Cent Water.	Age.	Dimensions of Cube.			Compressive Strength.		
		Height, Inches.	Surface, Inches.	Compressed Area, Square Inches.	Total Pounds.	Per Square Inch, Pounds.	Average Pounds per Square Inch.
28½	7 days	4.05	4.00×4.06	16.24	19,950	1228	1300
28½	"	4.00	4.09×4.08	16.68	22,600	1355	
28½	"	4.03	3.98×4.13	16.44	20,900	1271	
28½	"	3.96	4.03×4.07	16.40	19,980	1218	
28½	"	3.96	4.06×4.10	16.64	23,500	1412	
28½	1 month	3.96	4.15×4.04	16.77	27,100	1616	1790
28½	"	3.97	4.02×4.18	16.80	30,600	1821	
28½	"	3.96	4.04×4.07	16.44	33,500	2038	
28½	"	3.98	4.04×4.06	16.40	27,900	1701	
28½	"	4.00	4.13×4.00	16.69	29,500	1768	
28½	3 months	3.97	4.01×4.10	16.44	32,800	1995	2110
28½	"	3.99	4.05×4.05	16.40	34,100	2079	
28½	"	3.96	4.08×4.09	16.69	34,500	2067	
28½	"	3.98	4.01×4.18	16.76	29,200	2339	
28½	"	3.96	4.05×4.10	16.61	34,500	2077	
28½	12 months	3.96	4.03×4.19	16.89	33,600	1990	2190
28½	"	3.98	4.07×4.10	16.69	39,900	2390	
18	8 days	4.00	3.92×4.13	16.19	47,100	2910	3050
18	"	4.06	3.99×4.00	15.96	53,100	3330	
18	"	4.08	4.00×3.95	15.80	53,400	3380	
18	"	4.02	4.06×3.86	15.67	43,600	2780	
18	"	3.99	3.98×4.08	16.24	46,500	2860	
18	1 month	4.00	4.03×3.98	16.04	54,900	3420	3470
18	"	4.00	4.02×4.08	16.40	60,600	3700	
18	"	4.08	4.01×4.00	16.04	65,800	4100	
18	"	4.05	4.01×3.98	15.96	39,500	2480	
18	"	4.07	4.00×4.06	16.24	59,400	3660	
18	3 months	4.08	3.98×4.05	16.12	76,100	4720	4470
18	"	4.00	4.09×4.03	16.48	70,500	4280	
18	"	4.08	4.00×4.02	16.08	73,600	4580	
18	"	3.98	4.05×4.06	16.44	70,600	4290	

Report of Tests of Metals, etc., at Watertown Arsenal for 1902, pp. 376–377. 1903.

List of references on sand cement.—The following papers are of interest in this connection:

Butler, M. J. Silica Portland cement. Canadian Engineer, March, 1899.

Klein, O. H. Report on concrete foundations for pavements. 8vo, 58 pp. New York, 1903. (Much criticism of sand cements.)

Reeves, H. E. The effect of grinding mixed sand and cement. Technograph, May, 1896.

Smith, C. B. Sand cement. Brickbuilder, vol. 6, p. 280. 1897. (Tests of three Canadian brands. Important paper.)

TABLE 230.

COMPRESSIVE STRENGTH OF SAND-CEMENT MORTARS. (WATERTOWN ARSENAL.)

Brand.	Composition.	Per Cent Age.		Average Strength, Pounds per Square Inch.	
		Months.	Days.	In Air.	In Water.
Silica..........	Neat	..	7	1670	1880
"	"	1	..	2070	2830
"	"	3	..	2420	3110
"	1 cement, 1 sand	..	6	942	1090
"	" "	1	..	1460	1920
"	" "	3	..	1610	2340
"	1 cement, 2 sand	..	5	386	424
"	" "	1	..	424	708
"	" "	3	..	850	1120
"	1 cement, 3 sand	..	4	130	132
"	" "	1	..	219	360
"	" "	3	..	306	571

Report of Tests of Metals, etc., at Watertown Arsenal, 1902, p. 443.

TABLE 231.

MODULUS OF ELASTICITY OF SAND CEMENT. (WATERTOWN ARSENAL.)

Brand.	Mortar.	Weight per Cu. Ft. Pounds.	Time. Mos.	Time. Dys.	Ultimate Strength.	E.	Pounds per Square Inch.
Silica...	Neat	117.8	1	28	2520	$E(100–1000)$ $E(1000–2000)$	=1,607,000 =1,205,000
" ...	"	116.3	1	28	2400	$E(100–1000)$ $E(1000–2000)$	=1,475,000 =1,117,000
" ...	1 cement, 1 sand	126.9	1	29	1200	$E(100–1000)$	=1,286,000
" ...	1 cement, 2 sand	122.4	1	28	618	$E(100–500)$	= 909,000
" ...	1 cement, 3 sand	120.8	1	27	404	$E(100–400)$	= 632,000

Report of Tests of Metals, etc., at Watertown Arsenal, 1902, pp. 498–500.

References on sand cement—(*Continued*).

Anon. The manufacture and use of sand cement. Engineering News, April 16, 1896.

Anon. Le Silico-Portland on silico-cement. La Revue Technologique, Jan. 25, 1898.

Anon. The hydraulic experiment station of Cornell University. Engineering News, vol. 41, pp. 130–133. March 2, 1899. (Description of use of sand cement.)

Effect of heating.—The effect of high temperatures on cements or concretes is, in these days of fireproof construction, a matter of considerable interest to architects and engineers. In 1902 a series of tests along this line were carried out at Watertown Arsenal, some of which are summarized in Table 232, below.

These tests were made on 2-inch cubes of neat Portland cement, all being crushed at a period of 1 year, 1 month, and 16 days after making.

"The cubes for this series were prepared and set in air or in water for a period of one year to a year and a half before they were heated, and intervals ranging from four days to nearly four months intervened between the time of heating and the time of testing.

"The heated cubes were gradually raised to the temperatures recorded, and slowly cooled in dry sawdust or powdered asbestos. The time of heating was one hour, and the maximum temperature was maintained for one hour.

"Cubes which were set in water were dried off on a radiator for twenty-four hours before heating in the muffle to the temperatures recorded.

"During heating some of the cubes developed fine cracks, at first faintly shown, which enlarged after a few hours or days had elapsed. In other cases the cracks appeared more promptly. Among those which were heated to the higher temperatures of the series, which ranged from 200° to 1000° F., there were cubes so badly cracked as to be unsuitable for testing."

TABLE 232.

EFFECT OF HEATING ON COMPRESSIVE STRENGTH. (WATERTOWN ARSENAL.)

Brand.	Per Cent Water.	Heated to.	Compressive Strength, Pounds per Square Inch.
Alpha............	25	not heated	9167
"	25	200° F.	8830
"	25	300° F.	7920
"	25	400° F.	9190
"	25	500° F.	9400
"	25	600° F.	9000
"	25	700° F.	8217
"	25	800° F.	8730
"	25	900° F.	6060
Dyckerhoff.......	29	not heated	5017
"	29	600° F.	4347
"	29	700° F.	3483
"	29	800° F.	4280

Report of Tests of Metals, etc., at Watertown Arsenal, 1902, pp. 459–460.

Effects of salt and freezing.—The use of cement or concrete in buildings constructed during very cold weather has led to a long series of experiments, designed to determine the effects of using salt and other anti-freezing agents in the water used in mixing the mortar.

The results of a number of such tests are shown diagrammatically in Figs. 153 to 158 inclusive. The results as to strength are rather contradictory, but it seems probable that any addition of salt will decrease the ultimate tensile and compressive strength of the mortar in which

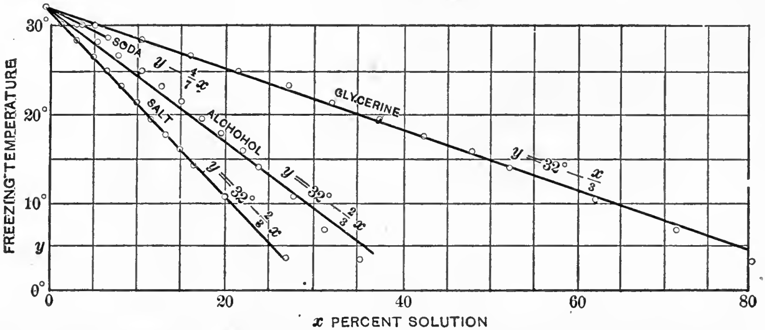

FIG. 153.*—Effect on the freezing-point of cement of various proportions of glycerine, alcohol, and salt. (Tetmajer.)

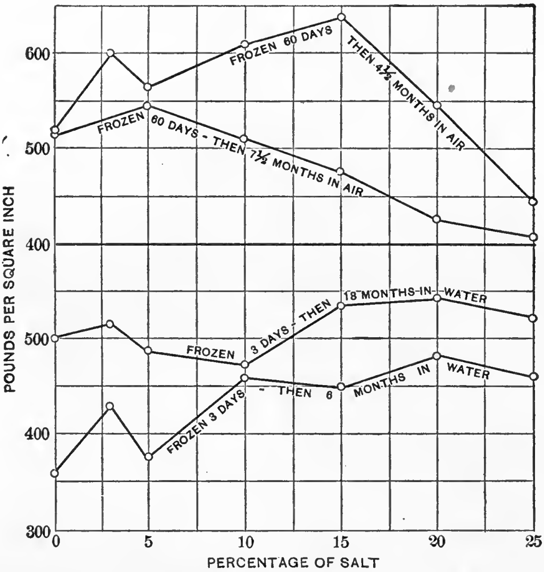

FIG. 154.†—Effect of salt on mortar, 1 cement:2 sand, made in freezing weather. (Sabin.)

it is used, but that for the lower percentages of salt this injurious effect may be slight enough to be safely disregarded.

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* From Johnson's "Materials of Construction", p. 615.
† Ibid., p. 617.

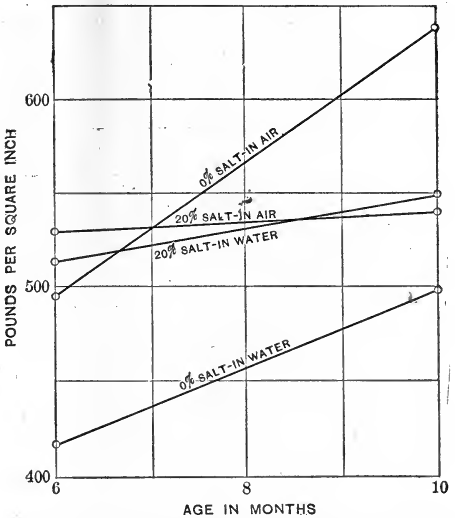

FIG. 155.*—Effect of salt on Portland-cement mortar, 1 cement:2 sand, made in freezing weather. (Sabin.)

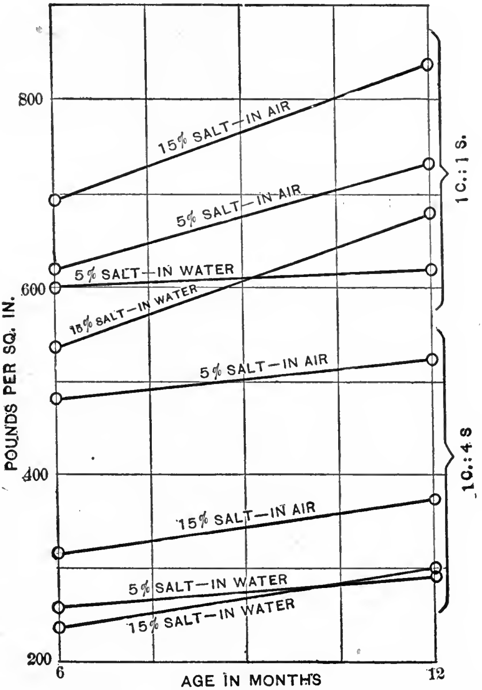

FIG. 156.†—Effect of salt on tensile strength of mortars, 1 cement:1 sand and 1 cement:4 sand. Those left in air remained frozen almost sixty days. Those put in water were first frozen in air for three days.

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* From Johnson's "Materials of Construction", p. 618. † Ibid., p. 619.

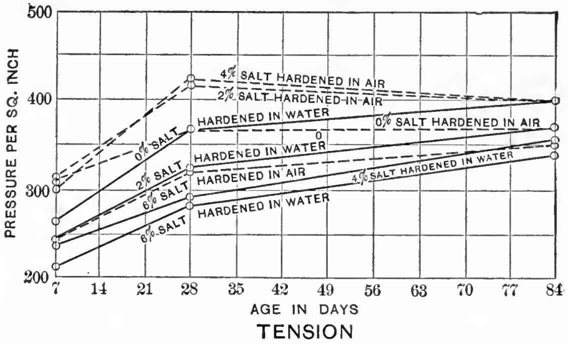

Fig. 157.*—Effect of salt on tensile strength of Portland-cement mortar. (Tetmajer.)

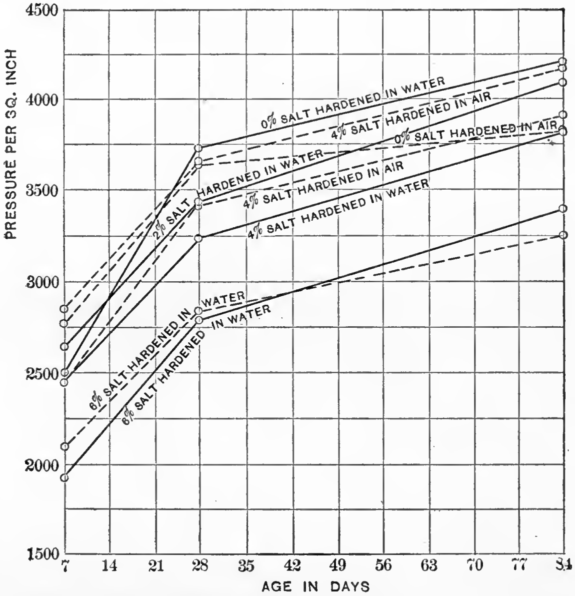

Fig. 158.*—Effect of salt on compressive strength of Portland-cement mortar. (Tetmajer.)

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* From Johnson's Materials of Construction", p. 620.

† Ibid.

Effects of exposure to sea-water.—Portland cement is not entirely satisfactory in its resistance to exposure to salt water, though in part this is often due to the use of porous mixtures which permit access of the water to the interior of the block of cement or concrete. The use of richer mixtures, or at least of a richer mixture for the surface of the block, will do away with many of the difficulties encountered. Aside from this, two methods of improvements have been advocated. One is to make the cement more resistant of itself by making it of such a chemical composition as will show the maximum resistance to the effects of salt water. This is the method of Le Chatelier, discussed below. The second method is, to add to the cement, trass, slag, or other puzzolanic material, in order that the lime liberated by the cement during hardening may be taken up and combined with the trass.

Le Chatelier considers that the aluminous compounds present in Portland cement are the direct cause of its destruction by sea-water. His theory, to account for this disintegration, is as follows: Free lime, liberated during the hardening of the cement, reacts with the magnesium sulphate always present in sea-water, to form calcium sulphate. This in turn reacts with the calcium aluminate of the cement to form a sulphaluminate of lime, which swells considerably on hydration and thus disintegrates the cement mass. The extent of the disintegration varies directly with the percentage of alumina present in the cement. Cements containing 1 or 2 per cent of alumina are, for example, practically unaffected by sea-water; while in cement containing as high as 7 or 8 per cent of alumina the swelling and consequent disintegration are very rapid.

If the alumina of a cement be replaced by an oxide not reacting with calcium sulphate, the stability of the cement in sea-water is greatly improved. Le Chatelier has demonstrated this by preparing cements in which the alumina was replaced by oxides of iron, chromium, cobalt, etc. All of these were more resistant than an alumina cement to the disintegrating effect of lime sulphate. The best effects were obtained when iron oxide was used, a cement corresponding in composition to $5SiO_2,Fe_2O_3,17CaO$ being found to be not only stable in presence of sea-water, but to possess excellent mechanical properties.

Deval's researches * on the effect of direct addition of calcium sulphate to various cements confirm the above theory. Each of the finely ground cements tested was completely hydrated by mixing with 50 per cent of water, and storing the mixture under water for three months out of

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* Abstract in Journ. Soc. Chem. Industry, vol. 21, p. 971–972.

contact with carbon dioxide. The mass was then dried, reground, mixed with half its weight of calcium sulphate and 33 per cent of water, and made up into rods, which were kept moist and protected from carbon dioxide by storage on moistened filter paper under a glass bell. At the end of three weeks the increase in length of the rods was measured, with the following results:

TABLE 233.

EFFECT OF ALUMINA.

Type of Cement.	Per Cent of Alumina in the Cement.	Per Cent of Elongation of the Rods.
Slag cement (Vitry).	15.5	27
Slag cement (Champignolles).	14.5	16
Grappier cement (Besses).	7.5	14
Portland cement.	6.2	12
Hydraulic lime (Besses).	4.7	4

It will be noted that the percentage of elongation of the rods, varied directly with the percentage of alumina in the cements tested, proving conclusively that the swelling was due to the action of the calcium sulphaluminate formed during the operation.

STANDARD METHODS OF TESTING, AM. SOC. C.E.

A Committee appointed by the American Society of Civil Engineers to examine methods of making cement tests, offered a progress report early in 1903, and a brief supplementary report in 1904. These reports have been combined and are presented below.

Standard Methods of Cement Testing.

SAMPLING.

1. *Selection of sample.*—The selection of the sample for testing is a detail that must be left to the discretion of the engineer; the number and the quantity to be taken from each package will depend largely on the importance of the work, the number of tests to be made and the facilities for making them.

2. The sample shall be a fair average of the contents of the packing; it is recommended that, where conditions permit, one barrel in every ten be sampled.

3. All samples should be passed through a sieve having 20 meshes per linear inch in order to break up lumps and remove foreign material;

this is also a very effective method for mixing them together in order to obtain an average. For determining the characteristics of a shipment of cement, the individual samples may be mixed and the average tested; where time will permit, however, it is recommended that they be tested separately.

4. *Method of sampling.*—Cement in barrels should be sampled through a hole made in the center of one of the staves, midway between the heads, or in the head, by means of an auger or a sampling iron similar to that used by sugar inspectors. If in bags, it should be taken from surface to center.

CHEMICAL ANALYSIS.

5. *Significance.*—Chemical analysis may render valuable service in the detection of adulteration of cement with considerable amounts of inert material, such as slag or ground limestone. It is of use, also, in determining whether certain constituents, believed to be harmful when in excess of a certain percentage, as magnesia and sulphuric anhydride, are present in inadmissible proportions. While not recommending a definite limit for these impurities, the committee would suggest that the most recent and reliable evidence appears to indicate that magnesia to the amount of 5 per cent, and sulphuric anhydride to the amount of 1.75 per cent, may safely be considered harmless.

6. The determination of the principle constituents of cement—silica, alumina, iron oxide and lime—is not conclusive as an indication of quality. Faulty character of cement results more frequently from imperfect preparation of the raw material or defective burning than from incorrect proportions of the constituents. Cement made from very finely ground material, and thoroughly burned, may contain much more lime than the amount usually present and still be perfectly sound. On the other hand, cements low in lime may, on account of careless preparation of the raw material, be of dangerous character. Further, the ash of the fuel used in burning may so greatly modify the composition of the product as largely to destroy the significance of the results of analysis.

7. *Method.*—As a method to be followed for the analysis of cement, that proposed by the Committee on Uniformity in the analysis of Materials for the Portland Cement Industry, of the New York Section of the Society for Chemical Industry, and published in the Journal of the Society for January 15, 1902, is recommended.

SPECIFIC GRAVITY.

8. *Significance.*—The specific gravity of cement is lowered by underburning, adulteration and hydration, but the adulteration must be in considerable quantity to affect the results appreciably.

9. Inasmuch as the differences in specific gravity are usually very small, great care must be exercised in making the determination.

10. When properly made, this test affords a quick check for underburning or adulteration.

11. *Apparatus and method.*—The determination of specific gravity is most conveniently made with Le Chatelier's apparatus. This consists of a flash of 120 cu. cm. (7.32 cu. inches) capacity, the neck of which is about 20 cm. (7.87 inches) long; in the middle of this neck is a bulb, above and beolw which are two marks; the volume between these marks is 20 cu. cm. (1.22 cu. inches). The neck has a diameter of about 9 mm. (0.35 inch), and is graduated into tenths of cubic centimeters above the bulb.

12. Benzine (62° Baumé naphtha), or kerosene free from water, should be used in making the determination.

13. The specific gravity can be determined in two ways:

(1) The flask is filled with either of these liquids to the lower mark and 64 grs. (2.25 ozs.) of powder, previously dried at 100° C. (212° F.) and cooled to the temperature of this liquid, is gradually introduced through the funnel (the stem of which extends into the flask to the top of the bulb), until the upper mark is reached. The difference in weight between the cement remaining and the original quantity (64 grs.) is the weight which has displaced 20 cu. cm.

14. (2) The whole quantity of the powder is introduced, and the level of the liquid rises to some division of the graduated neck. This reading plus 20 cu. cm. is the volume displaced by 64 gr. of the powder.

15. The specific gravity is then obtained from the formula:

$$\text{Specific gravity} = \frac{\text{Weight of cement}}{\text{Displaced Volume}}.$$

16. The flask, during the operation, is kept immersed in water in a jar, in order to avoid variations in the temperature of the liquid. The results should agree within 0.01.

17. A convenient method for cleaning the apparatus is as follows: The flask is inverted over a large vessel, preferably a glass jar, and shaken vertically until the liquid starts to flow freely, it is then held still in a vertical position until empty, the remaining traces of cement can be

removed in a similar manner by pouring into the flask a small quantity of clean liquid and repeating the operation.

18. More accurate determinations may be made with the picnometer.

FINENESS.

19. *Significance.*—It is generally accepted that the coarser particles in cement are practically inert, and it is only the extremely fine powder that possesses adhesive or cementing qualities. The more finely cement is pulverized, all other conditions being the same, the more sand it will carry and produce a mortar of a given strength.

20. The degree of final pulverization which the cement receives at the place of manufacture is ascertained by measuring the residue retained on certain sieves. Those known as the No. 100 and No. 200 sieves are recommended for this purpose.

21. *Apparatus.*—The sieves should be circular, about 20 cm. (7.87 inches) in diameter, 6 cm. (2.36 inches) high, and provided with a pan, 5 cm. (1.97 inches) deep, and a cover.

22. The wire cloth should be woven (not twilled) from brass wire having the following diameters:

No. 100, 0.0045 inch; No. 200, 0.0024 inch.

23. This cloth should be mounted on the frames without distortion; the mesh should be regular in spacing, and be within the following limits:

No. 100, 96 to 100 meshes to the linear inch.
No. 200, 188 to 200 " " " " "

24. Fifty grams (1.76 oz.) or 100 gr. (3.52 oz.) should be used for the test, and dried at a temperature of 100° C. (212° F.) prior to sieving.

25. *Method.*—The Committee, after careful investigation, has reached the conclusion that mechanical sieving is not as practicable or efficient as hand-work, and, therefore, recommends the following method:

26. The thoroughly dried and coarsely screened sample is weighed and placed on the No. 200 sieve, which, with pan and cover attached, is held in one hand in a slightly inclined position, and moved forward and backward, at the same time striking the side gently with the palm of the other hand, at the rate of about 200 strokes per minute. The operation is continued until not more than one tenth of 1 per cent passes through after one minute of continuous sieving. The residue is weighed, then placed on the No. 100 sieve and the operation repeated.

The work may be expedited by placing in the sieve a small quantity of large shot. The results should be reported to the nearest tenth of 1 per cent.

NORMAL CONSISTENCY.

27. *Significance.*—The use of a proper percentage of water in making the pastes * from which pats, tests of setting and briquettes are made, is exceedingly important, and affects vitally the results obtained.

28. The determination consists in measuring the amount of water required to reduce the cement to a given state of plasticity, or to what is usually designated the normal consistency.

29. Various methods have been proposed for making this determination, none of which has been found entirely satisfactory. The Committee recommends the following:

30. *Method. Vicat needle apparatus.*—This consists of a frame bearing a movable rod, with the cap at one end, and at the other end the cylinder, 1 cm. (0.39 inch) in diameter, the cap, rod, and cylinder weighing 300 gr. (10.58 oz.). The rod, which can be held in any desired position by a screw, carries an indicator, which moves over a scale (graduated to centimeters) attached to the frame. The paste is held by a conical, hard-rubber ring, 7 cm. (2.76 inches) in diameter at the base, 4 cm. (1.57 inches) high, resting on a glass plate about 10 cm. (3.94 inches) square.

31. In making the determination, the same quantity of cement as will be subsequently used for each batch in making the briquettes (but not less than 500 gr.) is kneaded into a paste, as described in Paragraph 58, and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained 6 inches apart; the ball is then pressed into the rubber ring through the larger opening, smoothed off, and placed on a glass plate (on its large end) and the smaller end smoothed off with a trowel; the paste, confined in the ring, resting on the plate, is placed under the rod bearing the cylinder, which is brought in contact with the surface and quickly released.

32. The paste is of normal consistency when the cylinder penetrates to a point in the mass 10 mm. (0.39 inch) below the top of the ring. Great care must be taken to fill the ring exactly to the top.

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* The term "paste" is used in this report to designate a mixture of cement and water, and the word "mortar" a mixture of cement, sand, and water.

33. The trial pastes are made with varying percentages of water until the correct consistency is obtained.

34. The Committee has recommended, as normal, a paste, the consistency of which is rather wet, because it believes that variations in the amount of compression to which the briquette is subjected in moulding are likely to be less with such a paste.

35. Having determined in this manner the proper percentage of water required to produce a neat paste of normal consistency, the proper percentage required for the sand mortars is obtained from an empirical formula.

36. The Committee hopes to devise such a formula. The subject proves to be a very difficult one, and, although the Committee has given it much study, it is not yet prepared to make a definite recommendation.

TIME OF SETTING.

37. *Significance.*—The object of this test is to determine the time which elapses from the moment water is added until the paste ceases to be fluid and plastic (called the "initial set"), and also the time required for it to acquire a certain degree of hardness (called the "final" or "hard set"). The former of these is the more important, since, with the commencement of setting, the process of crystallization or hardening is said to begin. As a disturbance of this process may produce a loss of strength, it is desirable to complete the operation of mixing and moulding or incorporating the mortar into the work before the cement begins to set.

38. It is usual to measure arbitrarily the beginning and end of the setting by the penetration of weighted wires of given diameters.

39. *Method.*—For this purpose the Vicat needle, which has already been described in Paragraph 30, should be used.

40. In making the test, a paste of normal consistency is moulded and placed under the rod, as described in Paragraph 31; this rod, bearing the cap at one end and the needle, 1 mm. (0.039 inch) in diameter, at the other, weighing 300 gr. (10.58 oz.). The needle is then carefully brought in contact with the surface of the paste and quickly released.

41. The setting is said to have commenced when the needle ceases to pass a point 5 mm. (0.20 inch) above the upper surface of the glass plate, and is said to have terminated the moment the needle does not sink visibly into the mass.

42. The test pieces should be stored in moist air during the test; this is accomplished by placing them on a rack over water contained

in a pan and covered with a damp cloth, the cloth to be kept away from them by means of a wire screen; or they may be stored in a moist box or closet.

43. Care should be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point reduces the area and tends to increase the penetration.

44. The determination of the time of setting is only approximate, being materially affected by the temperatures of the mixing water, the temperature and humidity of the air during the test, the percentage of water used, and the amount of moulding the paste receives.

STANDARD SAND.

45. The Committee recognizes the grave objections to the standard quartz now generally used, especially on account of its high percentage of voids, the difficulty of compacting in the moulds, and its lack of uniformity; it has spent much time in investigating the various natural sands which appeared to be available and suitable for use.

46. For the present, the Committee recommends the natural sand from Ottawa, Ill., screened to pass a sieve having 20 meshes per linear inch and retained on a sieve having 30 meshes per linear inch; the wires to have diameters of 0.0165 and 0.0112 inch, respectively, i.e., half the width of the opening in each case. Sand having passed the No. 20 sieve shall be considered standard when not more than 1 per cent passes a No. 30 sieve after one minute continuous sifting of a 500 gr. sample.

47. The Sandusky Portland Cement Company, of Sandusky, Ohio, has agreed to undertake the preparation of this sand, and to furnish it at a price only sufficient to cover the actual cost of preparation.

FORM OF BRIQUETTE.

48. While the form of the briquette recommended by a former Committee of the Society is not wholly satisfactory this Committee is not prepared to suggest any change, other than rounding off of the corners by curves of ½-inch radius.

MOULDS.

49. The moulds should be made of brass, bronze, or some equally non-corrodible material, having sufficient metal in the sides to prevent spreading during moulding

50. Gang moulds, which permit moulding a number of briquettes at one time, are preferred by many to single moulds; since the greater quantity of mortar that can be mixed tends to produce greater uniformity in the results.

51. The moulds should be wiped with an oily cloth before using.

MIXING.

52. All proportions should be stated by weight; the quantity of water to be used should be stated as a percentage of the dry material.

53. The metric system is recommended because of the convenient relation of the gram and the cubic centimeter.

54. The temperature of the room and the mixing water should be as near 21° C. (70° F.) as it is practicable to maintain it.

55. The sand and cement should be thoroughly mixed dry. The mixing should be done on some non-absorbing surface, preferably plate glass. If the mixing must be done on an absorbing surface it should be thoroughly dampened prior to use.

56. The quantity of material to be mixed at one time depends on the number of test pieces to be made; about 1000 gr. (35.28 oz.) makes a convenient quantity to mix, especially by hand methods.

57. The Committee, after investigation of the various mechanical mixing-machines, has decided not to recommend any machine that has thus far been devised, for the following reasons:

(1) The tendency of most cement is to "ball up" in the machine thereby preventing the working of it into a homogeneous paste; (2) there are no means of ascertaining when the mixing is complete without stopping the machine, and (3) the difficulty of keeping the machine clean.

58. *Method.*—The material is weighed and placed on the mixing table, and a crater formed in the center, into which the proper percentage of clean water is poured; the material on the outer edge is turned into the crater by the aid of a trowel. As soon as the water has been absorbed, which should not require more than one minute, the operation is completed by vigorously kneading with the hands for an additional 1½ minutes, the process being similar to that used in kneading dough. A sand-glass affords a convenient guide for the time of kneading. During the operation of mixing, the hands should be protected by gloves, preferably of rubber.

MOULDING.

59. Having worked the paste or mortar to the proper consistency, it is at once placed in the moulds by hand.

60. The Committee has been unable to secure satisfactory results with the present moulding-machines; the operation of machine moulding is very slow, and the present types permit of moulding but one briquette at a time, and are not practicable with the pastes or mortars herein recommended.

61. *Method.*—The moulds should be filled at once, the material pressed in firmly with the fingers and smoothed off with a trowel without ramming; the material should be heaped up on the upper surface of the mould, and, in smoothing off, the trowel should be drawn over the mould in such a manner as to exert a moderate pressure on the excess material. The mould should be turned over and the operation repeated.

62. A check upon the uniformity of the mixing and moulding is afforded by weighing the briquettes just prior to immersion, or upon removal from the moist closet. Briquettes which vary in weight more than 3 per cent from the average should not be tested.

STORAGE OF THE TEST PIECES.

63. During the first twenty-four hours after moulding, the test pieces should be kept in moist air to prevent them from drying out.

64. A moist closet or chamber is so easily devised that the use of the damp cloth should be abandoned if possible. Covering the test pieces with a damp cloth is objectionable, as commonly used, because the cloth may dry out unequally, and, in consequence, all the test pieces are not maintained under the same condition. Where a moist closet is not available, a cloth may be used and kept uniformly wet by immersing the ends in water. It should be kept from direct contact with the test pieces by means of a wire screen or some similar arrangement.

65. A moist closet consists of a soapstone or slate box; or a metal-lined wooden box, the metal lining being covered with felt and this felt kept wet. The bottom of the box is so constructed as to hold water, and the sides are provided with cleats for holding glass shelves on which to place the briquettes. Care should be taken to keep the air in the closet uniformly moist.

66. After twenty-four hours in moist air, the test pieces for longer periods should be immersed in water maintained as near 21° C. (70° F.)

as practicable; they may be stored in tanks or pans, which should be of non-corrodible material.

TENSILE STRENGTH.

67. The tests may be made on any standard machine. A solid metal clip is recommended. This clip is to be used without cushioning at the points of contact with the test specimen. The bearing at each point of contact should be ¼ inch wide, and the distance between the centers of contact on the same clips should be 1¼ inches.

68. Test pieces should be broken as soon as they are removed from the water. Care should be observed in centering the briquette in the testing-machine, as cross-strains, produced by improper centering, tend to lower the breaking strength. The load should not be applied too suddenly, as it may produce vibration, the shock from which often breaks the briquette before the ultimate strength is reached. Care must be taken that the clips and the sides of the briquettes be clean and free from grains of sand or dirt, which would prevent a good bearing. The load should be applied at the rate of 600 lbs. per minute. The average of the briquettes of each sample tested should be taken as the test, excluding any results which are manifestly faulty.

CONSTANCY OF VOLUME.

69. *Significance.*—The object is to develop those qualities which tend to destroy the strength and durability of a cement. As it is highly essential to determine such qualities at once, tests of this character are for the most part made in a very short time, and are known, therefore, as accelerated tests. Failure is revealed by cracking, checking, swelling, or disintegration, or all of these phenomena. A cement which remains perfectly sound is said to be of constant volume.

70. *Methods.*—Tests for constancy of volume are divided into two classes: (1) normal tests, or those made in either air or water maintained at about 21° C. (70° F.), and (2) accelerated tests, or those made in air, steam, or water at a temperature of 45° C. (115° F.) and upward. The test pieces should be allowed to remain twenty-four hours in moist air before immersion in water or steam, or preservation in air.

71. For these tests, pats, about 7½ cm. (2.95 inches) in diameter, 1¼ cm. (0.49 inch) thick at the center, and tapering to a thin edge, should be made, upon a clean glass plate [about 10 cm. (3.94 inches) square], from cement paste of normal consistency.

72. *Normal test.*—A pat is immersed in water maintained as near 210° C. (70° F.) as possible for twenty-eight days, and observed at intervals; the pat should remain firm and hard and show no signs of cracking, distortion, or disintegration. A similar pat is maintained in air at ordinary temperature and observed at intervals.

73. *Accelerated test.*—A pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel, for three hours.

74. To pass these tests satisfactorily, the pats should remain firm and hard, and show no signs of cracking, distortion, or disintegration.

75. Should the pat leave the plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate.

76. In the present state of our knowledge it cannot be said that cement should necessarily be condemned simply for failure to pass the accelerated tests, nor can a cement be considered entirely satisfactory simply because it has passed these tests.

CHAPTER XL.

SPECIFICATIONS FOR PORTLAND CEMENT.

Various specifications for Portland cement have been collected for insertion in the present chapter. These are of interest partly for comparison and partly to show the growth of intelligent treatment of this subject. The specifications of the American Society for Testing Materials will, it is probable, become the standard in this country.

New York State Canals, 1896.

The mortar and grout will be made of the best quality of Portland or natural hydraulic cement, as may be directed, and clean, sharp sand, in such proportions and made and used in such manner as may be required by the engineer.

No cement shall be used in any part of the masonry until the State engineer shall have examined, tried, and approved the same. It must be delivered in tight casks or bags, as the division or resident engineer may direct, and thereafter be properly protected from the weather.

The engineer to direct in what manner the sand shall be screened and worked, and washed, if necessary. When considered necessary by the engineer, salt shall be used with the mortar in such manner and proportions as he may direct.

Special directions shall be given by the engineer as to the delivery of cement and as to the time and facilities required for testing it previous to its use in the work. No cement will be used except in compliance with these directions. All facilities required by the engineer for securing tests must be afforded by the contractor. All cement must be stored in substantial water-proof structures from the time of delivery till used.

All cement offered for use in any work will be sampled by an agent of the State Engineer's Department. Samples will be collected immediately on delivery of cement at site of work, and contractors will promptly notify the engineer of the receipt of cement, in order that no delay may be had in the sampling thereof. All samples will be forwarded to the cement-testing office in Albany, and will be subjected to the following tests, and any cement failing on either of them will be rejected, though the further right is reserved to reject any and all cements the qualities of which have not become well known through prior use in State work or elsewhere.

Portland cement must be of the best quality and of such fineness that 95 per cent of the cement will pass through a sieve of 2500 meshes to the square inch, and 90 per cent through a sieve of 10,000 meshes per square inch. Portland cement when mixed neat and exposed one day in air and six days in water shall withstand a tensile strain of not less than 400 lbs. to the square inch, and when mixed in the ratio of 3 lbs. clean, sharp sand to 1 lb. of cement and exposed one day in air and six days in water, it shall withstand a tensile strain of not less than 125 lbs. per square inch.

Rapid-transit Subway, New York City, 1900–1901.

Fineness.—Ninety-eight per cent shall pass a No. 50 sieve and 90 per cent a No. 100 sieve.

Tensile strength.—At the end of one day in water after hard set, 150 lbs. neat; at the end of seven days, one day in air, six days in water, 400 lbs. neat; at the end of twenty-eight days, one day in air, twenty-seven days in water, 500 lbs. neat. When mixed 2 to 1 with quartz sand: At the end of seven days, one day in air, six days in water, 200 lbs.; at the end of twenty-eight days, one day in air, twenty-seven days in water, 300 lbs.

Chemical analyses.—Chemical analyses will be made from time to time, and cement furnished must show a reasonably uniform composition.

Soundness.—Tests for checking and cracking and for color will be made by molding, on plates of glass, cakes of neat cement about 3 inches in diameter, ½ inch thick in the center, and with very thin edges. One of these cakes when set perfectly hard shall be put in water and examined for distortion or cracks, and one shall be kept in air and examined for color, distortion, and cracks. Another cake shall be allowed to set in steam for twenty-four hours and then put in boiling water for twenty-four hours. Another cake shall be allowed to set hard in dry air for twenty-four hours and then put in boiling water for twenty-four hours. Such cakes should at the end of the tests still adhere to the glass and show neither cracks nor distortion. A briquette, in like manner, should be allowed to set hard in dry air for twenty-four hours, then boiled for twenty-four hours, be kept for five days in water, and show 350 lbs. tensile strength.

Department of Bridges, New York City, 1901.

(106) That all cement used on this work must be the best quality of imported or American Portland cement, manufactured by works of established reputation for furnishing a high-grade and uniform product. Cement must show a chemical analysis satisfactory to the engineer.

(107) That briquettes of neat cement exposed to air for twenty-four hours and then immersed in water for six days must have a tensile strength of at least 400 lbs. per square inch.

(108) That briquettes of mortar mixed in proportion of one part of cement to two and one half parts of dry sand, by weight, exposed to the air for twenty-four hours and then immersed in water for six days, must have a tensile strength of not less than 180 lbs. per square inch.

(109) That cement must be ground so fine that 90 per cent of it will pass through a sieve of 10,000 meshes per square inch.

(110) That pats of neat cement set in the air and then immersed in boiling water for twenty-four hours must show no checks or cracks.

(111) That cement must be sufficiently fresh to have lost no strength from age, but it must not be so fresh as to be "hot" and quick-setting. Neat cement at temperature of 70° F. must not take an initial set in less than thirty minutes, nor its final set in less than one hour.

(112) That the contractor must provide adequate storage and enough cement ahead to enable seven-day tests to be made before cement has to be used.

(113) That the contractor must furnish every reasonable facility to the inspectors for drawing samples of cement, and not less than ten days (holidays and Sundays excluded) must elapse between time of drawing the samples and using the cement.

(114) That cement must at all times be protected from dampness, air-currents, or other source of injury.

(115) That the laboratory tests given above are not final. Should the engineer at any time deem any lot of cement damaged or questionable in any respect, the same shall be rejected, although it may previously have met other tests.

(116) That cement must be delivered on the work in barrels of 375 lbs. net weight, or in sacks of 94 lbs. net weight.

Engineer Corps, U. S. Army, 1902.

(1) The cement shall be an American Portland, dry and free from lumps. By a Portland cement is meant the product obtained from the heating or calcining up to incipient fusion of intimate mixtures, either natural or artificial, or argillaceous with calcareous substances, the calcined product to contain at least 1.7 times as much of lime, by weight, as of the materials which give the lime its hydraulic properties, and to be finely pulverized after said calcination, and thereafter additions or substitutions for the purpose only of regulating certain properties of technical importance to be allowable to not exceeding 2 per cent of the calcined product.

(2) The cement shall be put up in strong, sound barrels well lined with paper, so as to be reasonably protected against moisture, or in stout cloth or canvas sacks. Each package shall be plainly labeled with the name of the brand and of the manufacturer. Any package broken or containing damaged cement may be rejected or accepted as a fractional package, at the option of the United States agent in local charge.

(3) Bidders will state the brand of cement which they propose to furnish. The right is reserved to reject a tender for any brand which has not established itself as a high-grade Portland cement and has not for three years or more given satisfaction in use under climatic or other conditions of exposure of at least equal severity to those of the work proposed.

(4) Tenders will be received only from manufacturers or their authorized agents.

(The following paragraph will be substituted for paragraphs 3 and 4 above when cement is to be furnished and placed by the contractor:

No cement will be allowed to be used except established brands of high-grade Portland cement which have been made by the same mill and in successful use under similar climatic conditions to those of the proposed work for at least three years.)

(5) The average weight per barrel shall not be less than 375 lbs. net. Four sacks shall contain one barrel of cement. If the weight as determined by test weighings is found to be below 375 lbs. per barrel, the cement may be rejected, or, at the option of the engineer officer in charge, the contractor may be required to supply, free of cost to the United States, an additional amount of cement equal to the shortage.

(6) Tests may be made of the fineness, specific gravity, soundness, time of setting, and tensile strength of the cement.

(7) **Fineness.**—Ninety-two per cent of the cement must pass through a sieve made of No. 40 wire, Stubbs gauge, having 10,000 openings per square inch.

(8) **Specific gravity.**—The specific gravity of the cement, as determined from a sample which has been carefully dried, shall be between 3.10 and 3.25.

(9) **Soundness.**—To test the soundness of the cement, at least two pats of neat cement mixed for five minutes with 20 per cent of water by weight shall be made on glass, each pat about 3 inches in diameter and $\frac{1}{2}$ inch thick at the center, tapering thence to a thin edge. The pats are to be kept under a wet cloth until finally set, when one is to be placed in fresh water for twenty-eight days. The second pat will be placed in water which will be raised to the boiling-point for six hours, then allowed to cool. Neither should show distortion or cracks. The boiling test may or may not reject at the option of the engineer officer in charge.

(10) **Time of setting.**—The cement shall not acquire its initial set in less than forty-five minutes and must have acquired its final set in ten hours.

(The following paragraph will be substituted for the above in case a quick-setting cement is desired:

The cement shall not acquire its initial set in less than twenty nor more than thirty minutes, and must have acquired its final set in not less than forty-five minutes nor in more than two and one-half hours.)

The pats made to test the soundness may be used in determining the time of setting. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire $\frac{1}{12}$ inch in diameter loaded to weigh $\frac{1}{4}$ lb. The final set has been acquired when the pat will bear, without being appreciably indented, a wire $\frac{1}{24}$ inch in diameter loaded to weigh 1 lb.

(11) **Tensile strength.**—Briquettes made of neat cement, after being kept in air for twenty-four hours under a wet cloth and the balance of the time in water, shall develop tensile strength per square inch as follows:

After seven days, 450 lbs.; after twenty-eight days, 540 lbs.

Briquettes made of 1 part cement and 3 parts standard sand, by weight, shall develop tensile strength per square inch as follows:

After seven days, 140 lbs.; after twenty-eight days, 220 lbs.

(In case quick-setting cement is desired, the following tensile strength shall be substituted for the above:

Neat briquettes: After seven days, 400 lbs.; after twenty-eight days, 480 lbs.

Briquettes of 1 part cement to 3 parts standard sand: After seven days, 120 lbs.; after twenty-eight days, 180 lbs.)

(12) The highest result from each set of briquettes made at any one time is to be considered the governing test. Any cement not showing an increase of strength in the twenty-eight-day tests over the seven-day tests will be rejected.

(13) When making briquettes neat cement will be mixed with 20 per cent of water by weight, and sand and cement with $12\frac{1}{2}$ per cent of water by weight. After being thoroughly mixed and worked for five minutes, the cement or mortar will be placed in the briquette mold in four equal layers, and each layer rammed and compressed by thirty blows of a soft brass or copper rammer three quarters of an inch in diameter (or seven tenths of an inch square, with rounded corners), weighing 1 lb. It is to be allowed to drop on the mixture from a height of about half an inch. When the ramming has been completed, the surplus cement shall be struck off and the final layer smoothed with a trowel held almost horizontal and drawn back with sufficient pressure to make its edge follow the surface of the mold.

(14) The above are to be considered the minimum requirements. Unless a cement has been recently used on work under this office, bidders will deliver a sample barrel for test before the opening of bids. If this sample shows higher tests than those given above, the average of tests made on subsequent shipments must come up to those found with the sample.

(15) A cement may be rejected in case it fails to meet any of the above requirements. An agent of the contractor may be present at the making of the tests, or, in case of the failure of any of them, they may be repeated in his presence. If the contractor so desires, the engineer officer in charge may, if he deem it to the interest of the United States, have any or all of the tests made or repeated at some recognized standard testing laboratory in the manner herein specified. All expenses of such tests to be paid by the contractor. All such tests shall be made on samples furnished by the engineer officer from cement actually delivered to him.

U. S. Reclamation Service, 1904.

1. **Definition.**—The cement shall be high-grade Portland cement. By the term Portland cement is to be understood the material obtained by finely pulverized clinker produced by burning to semi-fusion an intimate mixture of finely ground calcareous and argillaceous materials.

2. **Composition.**—It must be of normal composition, in which the proportion of the sum of calcium oxide and alkalies to the sum of the silica, alumina, and ferric oxide must not be less than 1.7 to 1 nor more than 2.2 to 1. It shall not contain over 3 per cent of magnesia nor $2\frac{1}{2}$ per cent of sulphate of lime. But in certain cases where such amounts of these substances are objectionable the engineer in charge may specify lower percentages. Its freedom from uncombined lime shall be determined as in article 12. The question of adulteration may be determined either by chemical analyses or by inspection of the process at the factory.

3. **Bids.**—Bids will be received only from manufacturers or their authorized agents, and the name of the brand offered shall in all cases be stated.

4. **Weight per barrel or sack.**—The average weight per barrel shall not be less than 375 lbs. net. Four sacks shall contain 1 barrel of cement. If the weight as determined by test weighings is found to be below 375 pounds per barrel, the contractor may be required to supply, free of cost to the United States, an additional amount of cement equal to the shortage.

5. **Barrels; damaged cement.**—If the cement is delivered in barrels, the barrels shall be strong and lined with paper, and the cement shall be free from lumps. Any package that is broken or that contains damaged cement may be rejected by the United States agent in local charge.

6. **Sampling.**—Samples of cement are to be taken from the barrels or sacks with a sampling-tube in such manner as to secure fair average of the packages. They are to be taken from every tenth barrel or fortieth sack and numbered, and the packages from which they are taken to be sealed and corresponding numbers attached for future identification. The quantities taken are to be kept separate and tested separately. Where the results of tests indicate variation in the quality of the cement, additional barrels or sacks will be sampled and tested.

7. **Aeration and testing.**—No cement shall be shipped until at least sixty days after its manufacture, except that in case of an emergency, and with the approval of the engineer in charge, a shorter time may be allowed, but if the cement shows indications of unsoundness, a longer

time may be required. The contractor shall keep in storage, in sacks or barrels, such stocks of cement as the engineer shall require, free of expense to the United States, for sampling and testing during a period of twenty-eight days.

8. **Shipment.**—The engineer shall give notice in writing to the contractor of the approximate requirements for cement shipments and of dates for sampling. In all cases the contractor shall be responsible for the delivery of the cement in good condition at the place of consignment.

9. **Factory inspection.**—The Government engineer, or his authorized agent, shall at all times have liberty to inspect the materials, process of manufacture, and daily laboratory records of analyses and tests at the cement works.

10. **Fineness.**—Ninety-five per cent by weight must pass through a No. 100 sieve having 10,000 meshes per square inch, the wire to be No. 40 Stubbs wire gauge; and 75 per cent by weight must pass through a No. 200 sieve having 40,000 meshes per square inch, the wire to be No. 48 Stubbs wire gauge.

11. **Specific gravity.**—The specific gravity of the cement shall not be less than 3.

12. **Soundness.**—Pats are to be made of neat mortar of normal consistency. The pats are to be molded on glass plates. They are to be circular in shape, 3 inches in diameter, $\frac{1}{2}$ inch thick in the center, and drawn to a thin edge at their circumference, and are to be kept under a wet coth, or in a moist atmosphere, until finally set. One pat is to be put in water, the temperature of which is to be raised to the boiling-point and kept at that point for six hours. If the pat softens, cracks, warps, or disintegrates, the cement is unsound.

13. **Time of setting.**—The cement shall not acquire its initial set in less than forty-five minutes, and must acquire its final set within twelve hours. The pats made to test the soundness may be used in determining the time of setting. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire $\frac{1}{12}$ inch in diameter loaded to weigh one fourth pound. The final set has been acquired when the pat will bear, without being appreciably indented, a needle $\frac{1}{24}$ inch in diameter loaded to weigh one pound.

14. **Making briquettes.**—In making briquettes, neat cement mortar of normal consistency will be used. The mortar will be thoroughly mixed with a trowel and kneaded into the molds with the thumbs, a blunt stick, or a plunger. Six briquettes will be made from each sample. In making sand briquettes, the proportions shall be one part by weight of cement to three parts of standard crushed quartz sand and about

half as much water as is used for neat briquettes. Six briquettes will be made from each sample.

15. **Tensile strength.**—The neat briquettes prepared as specified above shall stand a minimum tensile strain per square inch as follows:

For one day in air and six days in water	450 lbs.
For one day in air and twenty-seven days in water	550 "

The sand-mortar briquettes, prepared as specified above, shall stand a minimum tensile strain per square inch as follows:

After one day in air and six days in water	175 lbs.
After one day in air and twenty-seven days in water	225 "

16. **Requirements.**—The above are to be considered the minimum requirements. The neat tests are to be considered of less value than those of sand and cement. The twenty-eight-day tests must always be higher than the seven-day tests. A cement may be rejected which fails to meet any of the above requirements.

Canadian Society of Civil Engineers.*

The whole of the cement is to be well-burned pure Portland cement, of the best quality, free from free lime, slag dust, or other foreign material.

(1) **Fineness.**—The cement shall be ground so fine that the residue on a sieve of 10,000 meshes to the square inch shall not exceed 10 per cent of the whole by weight, and the whole of the cement shall pass a sieve of 2500 meshes to the square inch.

(2) **Specific gravity.**—The specific gravity of the cement shall be at least 3.09, and shall not exceed 3.25 for fresh cement, the term "fresh" being understood to apply to such cements as are not more than two months old.

(3) **Tests.**—The cement shall be subjected to the following tests:

(*a*) *Blowing test.*—Mortar pats of neat cement thoroughly worked shall be troweled upon carefully cleaned 5-inch by 2½-inch ground-glass plates. The pats shall be about ½ inch thick in the center and worked off to the sharp edges at the four sides. They shall be covered with a damp cloth and allowed to remain in the air until set, after which they shall be placed in vapor in a tank in which the water is heated to a temperature of 130° F. After remaining in the vapor six hours,

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* Proposed Canadian standard specifications for Portland cement. Cement, vol. 4, pp. 98–99. May, 1903.

including the time of setting in air, they shall be immersed in the hot water and allowed to remain there for eighteen hours. After removal from the water the samples shall not be curled up, shall not have fine hair cracks, nor large expansion cracks, nor shall they be distorted. If separated from the glass, the samples shall break with a sharp, crisp ring.

(*b*) *Tensile est* (*neat cement*).—Briquettes made of neat cement mixed with about 20 per cent of water, by weight, after remaining one day in air, in a moist atmosphere, shall be immersed in water, and shall be capable of sustaining a tensile stress of 250 lbs. per square inch after submersion for two days, 400 lbs. per square inch after submersion for six days, 500 lbs. per square inch after submersion for twenty-seven days. The tensile test shall be considered as the average of the strength of five briquettes, and any cement showing a decrease in tensile strength on or before the twenty-eighth day shall be rejected. (*Sand and cement.*)—The sand for standard tests shall be clean quartz, crushed so that the whole shall pass through a sieve of 400 meshes to the square inch, but shall be retained on a sieve of 900 meshes per square inch. The sand and cement shall be thoroughly mixed dry, and then about 10 per cent of their weight of water shall be added, when the briquettes are to be formed in suitable molds. After remaining in a damp chamber for twenty-four hours the briquettes shall be immersed in water, and briquettes made in the proportion of one of cement to three of sand, by weight, shall bear a tensile stress of 125 lbs. per square inch after submersion for six days, and 200 lbs. per square inch after submersion for twenty-eight days. Sand and cement briquettes shall not show a decrease in tensile strength at the end of twenty-eight days or subsequently.

(4) The manufacturer shall, if required, supply chemical analyses of the cement.

(5) **Packing.**—The cement shall be packed either in stout air- and water-tight casks, carefully lined with strong brown paper, or in strong air- and water-tight bags.

(6) The manufacturer shall give a certificate with each shipment of cement, stating (1) the date of manufacture; (2) the tests and analyses which have been obtained for the cement in question at the manufacturer's laboratory; (3) that the cement does not contain any adulteration.

Concrete-steel Engineering Company.*

No cement will be allowed to be used except established brands of high-grade Portland cement which has been in successful use under similar conditions to the work proposed for at least three years, and has been seasoned or subjected to aeration for at least thirty days before leaving the factory. All cement shall be dry and free from lumps, and immediately upon receipt shall be stored in a dry, well-covered, and ventilated place thoroughly protected from the weather. If required the contractor shall furnish a certified statement of the chemical composition of the cement and of the raw material from which it is manufactured.

The fineness of the cement shall be such that at least 90 per cent will pass through a sieve of No. 40 wire, Stubbs gauge, having 10,000 openings per square inch, and at least 75 per cent will pass through a sieve of No. 45 wire, Stubbs gauge, having 40,000 openings per square inch.

Samples for testing may be taken from every bag or barrel, but usually for tests of 100 barrels a sample will be taken from every tenth barrel. The samples will be mixed thoroughly together while dry, and the mixture be taken as the sample for test.

Tensile tests will be made on specimens prepared and maintained until tested at a temperature not less than 60° F. Each specimen will have an area of 1 square inch at the breaking section and after being allowed to harden in moist air for twenty-four hours will be immersed and maintained under water until tested.

The sand used in preparing test specimens shall be clean, sharp, crushed quartz retained on a sieve of 30 meshes per lineal inch, and passing through a sieve of 20 meshes per lineal inch. In test specimens of one cement and three sand, no more than 12 per cent of water by weight shall be used. Specimens prepared from a mixture of one part cement and three parts sand, parts by weight, shall after seven days develop a tensile strength of not less than 170 lbs. per square inch, and not less than 240 lbs. per square inch after twenty-eight days. Cement mixed neat from 20 per cent to 25 per cent of water to form a stiff paste shall, after 30 minutes, be appreciably indented by the end of a wire inch $\frac{1}{12}$ in diameter loaded to weigh $\frac{1}{4}$ lb. Cement made into

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* The specifications from which this section is taken were published in Cement, vol. 4, pp. 105–108, May, 1903. They are for concrete-steel structures on the Melan, Thacher, and Von Emperger patents.

thin pats on glass plates shall not crack, scale, or warp under the following treatment: Three pats will be made and allowed to harden in moist air at from 60° to 70° F.; one of these will be placed in fresh water for twenty-eight days, another will be placed in water which will be raised to the boiling-point for six hours and then allowed to cool, and the third is to be kept in the air of the prevailing outdoor temperature.

British Standard Specifications.*

Quality and preparation.—(1) The cement is to be prepared by intimately mixing together calcareous and argillaceous materials, burning them at a clinkering temperature and grinding the resulting clinker. No addition of any material is to be made after burning, except when desired by the manufacturer, and if not prohibited in writing by the consumer, in which case calcium sulphate or water may be used. The cement, if watered, shall contain not more than 2 per cent of water, whether that water has been added or has been naturally absorbed from the air. If calcium sulphate is used, not more than 2 per cent calculated as anhydrous calcium sulphate of the weight of the cement shall be added.

Sampling and preparation for testing and analysis.—(2) As soon as the cement has been bulked at the maker's works,† or on the works in connection with which the material is to be used, at the consumer's option, samples for testing are to be taken from each parcel, each sample consisting of cement from at least twelve different positions in the same heap, so distributed as to insure, as far as is practicable, a fair average sample of the whole parcel, all to be mixed together and the sample for testing to be taken therefrom.

(3) Before gauging the tests, the sample so obtained is to be spread out for a depth of 3 inches for twenty-four hours, in a temperature of 58° to 64° F.

(4) In all cases where consignments are of 100 tons and upwards samples selected as above from each consignment, either at the maker's works or after delivery at the works where the cement is to be used, are to be sent for expert testing and for chemical analysis. In no case is cement so tested and analyzed to be accepted or used unless

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* British standard specifications for Portland cement. Engineering News, vol. 53, pp. 227–228. March 2, 1905.

† Should the consumer desire to stipulate for any special quantity, the size of the heap should be stated.

previously certified in writing by the consumer to be of satisfactory quality. Payment for such tests and analyses to be made by the consumer, the manufacturer supplying the cement required for the same free of charge. When consignments of less than 100 tons have to be supplied, the maker shall, if required, give certificates for each delivery, to the effect that such cement complies with the terms of this standard specification, with regard to quality, tests, and chemical analyses, no payment being made by the consumer for such certificate nor for the making of such tests and analyses.

(5) Should it be deemed more convenient by the consumers that the samples for testing should be taken at the makers' works before delivery, the latter are, in that event, to afford full facilities to the inspector who may be appointed by the consumers to sample the cement as he may desire at the makers' works, and subsequently to identify each parcel as it may be dispatched, with that sampled by him. No parcel is to be sent away unless a written order has been previously received by the makers from the said consumer to the effect that the material in question has been approved.

Fineness and sieves.—(6) The cement shall be ground to comply with the following degrees of fineness, viz.:

The residue on a sieve 76×76=5776 meshes per square inch is not to exceed 5 per cent.

The residue on a sieve 180×180=32,400 meshes per square inch is not to exceed $22\frac{1}{2}$ per cent.

The sieves are to be prepared from standard wire; the size of the wire for the 5776 mesh is to be .0044 inch and for the 32,400 mesh .0018 inch. The wire shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

Specific gravity.—(7) The specific gravity of the cement shall be not less than 3.15 when sampled and hermetically sealed at the makers' works, nor less than 3.10 if sampled after delivery to the consumer.

Chemical composition.—(8) The cement is to comply with the following conditions as to its chemical composition. There shall be no excess of lime, that is to say, the proportion of lime shall be not greater than is necessary to saturate the silica and alumina present. The percentage of insoluble residue shall not exceed 1.5 per cent; that of magnesia shall not exceed 3 per cent, and that of sulphuric anhydride shall not exceed 2.5 per cent.

Tensile tests.—(9) The quantity of water used in gauging shall be appropriate to the quality of the cement, and shall be so proportioned that when the cement is gauged it shall form a smooth, easily worked paste that will leave the trowel cleanly in a compact mass. Fresh water is to be used for gauging, the temperature thereof, and of the test-room at the time the said operations are performed, being from 58° to 64° F.

The cement gauged as above is to be filled, without mechanical ramming, into molds; each mold resting upon an iron plate until the cement has set. When the cement has set sufficiently to enable the mold to be removed without injury to the briquette, such removal is to be effected. The said briquettes shall be kept in a damp atmosphere and placed in fresh water twenty-four hours after gauging and kept there until broken, the water in which the test briquettes are submerged being renewed every seven days and the temperature thereof maintained between 58° and 64° F.

Neat tests.—(10) Briquettes of neat cement are to be gauged for breaking at seven and twenty-eight days, respectively, six briquettes for each period. The average tensile strength of the six briquettes shall be taken as the accepted tensile strength for each period. For breaking, the briquette is to be held in strong metal jaws, the briquettes being slightly greased where gripped by the jaws. The load must then be steadily and uniformly applied, starting from zero, increasing at the rate of 100 lbs. in twelve seconds. The briquettes are to bear on the average not less than the following tensile stresses before breaking:

7 days from gauging	400 lbs. per square inch of section.
28 days from gauging	500 lbs. per square inch of section.

The increase from seven to twenty-eight days shall not be less than:

25% when the 7-day test falls between 400 to 450 lbs. per square inch.
20% when the 7-day test falls between 450 to 500 lbs. per square inch.
15% when the 7-day test falls between 500 to 550 lbs. per square inch.
10% when the 7-day test falls between 550 lbs. per square inch or upwards.

Sand tests.—(11) The cement shall also be tested by means of briquettes prepared from one part of cement to three parts by weight of dry standard sand, the said briquettes being of the shape described for the neat-cement tests; the mode of gauging, filling the molds, and breaking the briquettes is also to be similar. The proportion of water used shall be such that the mixture is thoroughly wetted, and there shall be no superfluous water when the briquettes are formed. The cement and sand briquettes are to bear the following tensile stresses:

7 days from gauging	120 lbs. per square inch of section.
28 days from gauging	225 lbs. per square inch of section.

The increase from seven to twenty-eight days shall not be less than 20 per cent.

The standard sand referred to above is to be obtained from Leighton Buzzard. It must be thoroughly washed, dried, and pass through a sieve of 20×20 meshes per square inch, and must be retained on a sieve of 30×30 meshes per square inch, the wires of the sieve being .0164-inch and .0108-inch respectively.

Setting-time.—(12) There shall be three distinct gradations of setting-time, which shall be designated as "quick", "medium", and "slow".*

Quick.—The setting-time shall not be less than ten minutes or more than thirty minutes.

Medium.—The setting-time shall not be less than half an hour or more than two hours.

Slow.—The setting-time shall not be less than two hours or more than five hours.*

The temperature of the air in the test-room at the time of gauging and of the water used is to be between 58° and 64° F.

The cement shall be considered as "set" when a needle having a flat end $\frac{1}{16}$ inch square, weighing in all $2\frac{1}{2}$ lbs., fails to make an impression when its point is applied gently to the surface.

Soundness.—(13) The cement shall be tested by the Le Chatelier method, and is in no case to show a greater expansion than 12 millimeters after twenty-four hours' aeration and 6 millimeters after 7 days' aeration.

Note.—The apparatus for conducting the Le Chatelier test consists of a small split cylinder of spring brass or other suitable metal of 0.5 millimeter (.0197 in.) in thickness, 30 millimeters (1.1875 inches) internal diameter, and 30 millimeters high, forming the mold, to which on either side of the split are attached two indicators 165 millimeters (6.5 inches) long from the center of the cylinder, with pointed ends.

In conducting the test the mold is to be placed upon a small piece of glass and filled with cement gauged in the usual way, care being taken to keep the edges of the molds gently together while this operation is being performed. The mold is then covered with another glass plate, a small weight is placed on this, and the mold is immediately placed in water at 58° to 64° F. and left there for twenty-four hours.

The distance separating the indicator points is then measured and the mold placed in cold water, which is brought to the boiling-point in

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* When a specially slow-setting cement is required the minimum time of setting shall be specified.

15 to 30 minutes and kept boiling for six hours. After cooling, the distance between the points is again measured; the difference between the two measurements represents the expansion of the cement, which must not exceed the limits laid down in this specification.

(14) The tests and analyses hereinbefore referred to shall in no case relate to a larger quantity of cement than 250 tons sampled at one time.

Acceptance.—(15) No cement is to be approved or accepted unless it fully complies with the foregoing conditions.

American Society for Testing Materials, 1904.

GENERAL OBSERVATIONS.

1. These remarks have been prepared with a view of pointing out the pertinent features of the various requirements and the precautions to be observed in the interpretation of the results of the tests.

2. The committee would suggest that the acceptance or rejection under these specifications be based on tests made by an experienced person having the proper means for making the tests.

3. **Specific gravity.**—Specific gravity is useful in detecting adulteration or underburning. The result of tests of specific gravity are not necessarily conclusive as an indication of the quality of the cement, but when in combination with the results of other tests may afferd valuable indications.

4. **Fineness.**—The sieves should be kept thoroughly dry.

5. **Time of setting.**—Great care should be exercised to maintain the test pieces under as uniform conditions as possible. A sudden change or wide range of temperature in the room in which the tests are made, a very dry or humid atmosphere, and other irregularities vitally affect the rate of setting.

6. **Tensile strength.**—Each consumer must fix the minimum requirements for tensile strength to suit his own conditions. They shall, however, be within the limits stated.

7. **Constancy of volume.**—The tests for constancy of volume are divided into two classes, the first normal, the second accelerated. The latter should be regarded as a precautionary test only, and not infallible. So many conditions enter into the making and interpreting of it that it should be used with extreme care.

8. In making the pats the greatest care should be exercised to avoid initial strains due to molding or to too rapid drying out during the first twenty-four hours. The pats should be preserved under the most

uniform conditions possible, and rapid changes of temperature should be avoided.

9. The failure to meet the requirements of the accelerated tests need not be sufficient cause for rejection. The cement may, however, be held for twenty-eight days and a retest made at the end of that period. Failure to meet the requirements at this time should be considered sufficient cause for rejection, although in the present state of our knowledge it cannot be said that such failure necessarily indicates unsoundness, nor can the cement be considered entirely satisfactory simply because it passes the tests.

STANDARD SPECIFICATIONS FOR CEMENT.

1. **General conditions.**—All cement shall be inspected.

2. Cement may be inspected either at the place of manufacture or on the work.

3. In order to allow ample time for inspecting and testing, the cement should be stored in a suitable weather-tight building having the floor properly blocked or raised from the ground.

4. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment.

5. Every facility shall be provided by the contractor and a period of at least twelve days allowed for the inspection and necessary tests.

6. Cement shall be delivered in suitable packages with the brand and name of manufacturer plainly marked thereon.

7. A bag of cement shall contain 94 lbs. of cement net. Each barrel of Portland cement shall contain 4 bags, and each barrel of natural cement shall contain 3 bags, of the above net weight.

8. Cement failing to meet the seven-day requirements may be held awaiting the results of the twenty-eight-day tests before rejection.

9. All tests shall be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the society Jan. 21, 1903, and amended Jan. 20, 1904, with all subsequent amendments thereto.

10. The acceptance or rejection shall be based on the following requirements:

PORTLAND CEMENT.

18. **Definition.**—This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to

which no addition greater than 3 per cent has been made subsequent to calcination.

19. **Specific gravity.**—The specific gravity of the cement, thoroughly dried at 100° C., shall be not less than 3.10.

20. **Fineness.**—It shall leave by weight a residue of not more than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200-sieve.

21. **Time of setting.**—It shall develop initial set in not less than thirty minutes, but must develop hard set in not less than one hour, nor more than ten hours.

22. **Tensile strength.**—The minimum requirements for tensile strength for briquettes one inch square in section shall be within the following limits, and shall show no retrogression in strength within the periods specified:

Neat Cement.

Age.	Strength.
24 hours in moist air	150—200 lbs.
7 days (1 day in air, 6 days in water)	450—550 "
28 days (1 day in air, 27 days in water)	550—650 "
One Part Cement, Three Parts Sand:	
7 days (1 day in moist air, 6 days in water)	150—200 "
28 days (1 day in moist air, 27 days in water)	200—300 "

23. **Constancy of volume.**—Pats of neat cement about three inches in diameter, one half inch thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(*a*) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

(*b*) Another pat is kept in water maintained as near 70° F. as practicable, and observed at intervals for at least 28 days.

(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

24. These pats, to satisfactorily pass the requirements, shall remain firm and hard and show no signs of distortion, checking, cracking or disintegration.

25. **Sulphuric acid and magnesia.**—The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of magnesia (MgO).

PART VII. PUZZOLAN CEMENTS.

CHAPTER XLI.

PUZZOLANIC MATERIALS IN GENERAL.

PUZZOLANIC materials include all those natural or artificial materials which are capable of forming hydraulic cements on being simply mixed with lime, without the use of heat. Many materials possess this property, but relatively few have ever attained to sufficient commercial importance to be discussed here. In composition the puzzolanic materials are largely made up of silica and alumina, usually with more or less iron oxide; some, as the slags used in cement-manufacture, carry also notable percentages of lime. As might be inferred from this composition, most of the puzzolanic materials possess hydraulicity to a greater or less degree of themselves, but the addition of lime usually greatly increases their hydraulic power.

The term *puzzolan*, here adopted for this group of cementing materials, is a corruption of the adjective form of the name *pozzuolana*. It has no particular etymological excuse for existence, but will be accepted in this volume for the sake of uniformity, as it seems to have been adopted by various authorities in the United States.

Natural Puzzolanic Materials.

Natural puzzolanic materials are quite widely distributed, though they have never attained much commercial importance, save in Europe. As regards their origin, they are of two classes: In the first class may be included all those which are the direct products of volcanic action, the material being a fine volcanic ash or dust deposited either on the slopes of the volcano or carried by the wind to lakes or streams in which the ash is deposited. This group includes the more active puzzolanic materials, its chief representatives being pozzuolana proper, santorin, tosca, tetin and trass. It may be noted that in origin materials of this class resemble closely the granulated slags used in slag-cement manufacture both volcanic ashes and granulated slags being due to the processes of (1) fusion of a silico-aluminous material, and (2) rapid cooling of the resulting product by ejection into air or immersion in water. The second class includes a number of less important (because less active) hydraulic materials, such as arênes, psammites, etc., which are materials resulting from the decay of certain igneous rocks.

The principal natural puzzolanic materials will be discussed separately, in the following order: Pozzuolana (tosca, tetin), trass, santorin, arênes.

Pozzuolana.—Pozzuolana derives its name from the little town of Pozzuoli, located a few miles west of Naples, at which point the material was first obtained by the Greek colonists, and at a later date by the Romans. The material has also been exploited at other points near Rome and Naples.

TABLE 234.

ANALYSES OF POZZUOLANA FROM ITALY.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O
1	58.58	22.74		4.06	1.37			
2	52.66	14.33	10.33	7.66	3.86	4.13		7.03
3	44.5	15.0	12.0	8.8	4.7	1.4	4.0	9.2
4	63.18	19.8		5.68	0.35			
5	60.91	21.28	4.76	1.90	0.00	4.37	6.23	
6	44.0	10.5	29.5	10.0	tr.	1.00		2.5
7	44.5	15.75	16.3	8.96	tr.	11.0		3.5
8	46.0	16.5	15.5	10.0	3.0	4.0		5.0
9	44.5	15.5	12.5	9.5	4.4	10.27		3.33
10	39.0	14.0	13.0	18.0	3.0	11.0		
11	56.31	15.23	7.11	1.74	1.36	6.54	2.84	6.12

1. Pozzuolana, Rome. Stanger and Blount, Mineral Industry, vol. 5, p. 71.
2. " St. Paul's Caves. Thoyn, Dict. App. Chem., 3d ed., vol. 1, p. 475.
3. " Civita Vecchia. Berther, Anal. Gillmon, Limes, Cements, and Mortars, p. 125.
4. " Naples. Stanger and Blount, Mineral Industry, vol. 5, p. 71.
5. " " . Stengel, Anal. Zervas, School of Mines Quart. vol. 18, p. 230.
6. " Vesuvius. Brown. Thorpe, Dict. App. Chem., 3d ed., vol. 1, p. 475.
7. " " " " " " " 3d ed., vol. 1, p. 475.
8. " " Dark gray. " " " " 3d ed., vol. 1, p. 475.
9. " " Light gray. " " " " 3d ed., vol. 1, p. 475.
10. Lava, Vesuvius, 1868. Thorpe, Dict. App. Chem., 3d ed., vol. 1, p. 475.
11. Tuff, Monte Nuova. Merrill, Rocks, Rock Weathering and Soils, p. 141.

Most of the Italian pozzuolana is obtained from small open cuts, or pits, though some of these workings are now of great depth. Those of Trentaremi, for example, are about 600 feet deep. The various deposits differ greatly in the quality of the materials obtained from them. Care should therefore be exercised in selecting a spot for exploitation, and sorting of the material dug would be advisable in order to keep the product of uniformly high grade. After extraction the material is screened and ground. In addition it is occasionally slightly roasted, which process increases its hydraulic properties. Carelessness, both in the mining and in the later preparation of the pozzuolana, has brought the Italian article somewhat into disrepute among European engineers. In consequence it is losing ground with respect both to pozzuolana from the Azores and to trass from Rhenish Prussia.

Pozzuolana is also obtained at a number of localities in southeastern France. These localities occur mostly in three areas: (1) in the Auvergne Mountains, lying in the Departments of Puy de Dome and Cantal; (2) in the Mountains du Vivarais, between Haute Loire and Ardêche; and (3) in the Department of l'Herault, near the Gulf of Lyons.

TABLE 235.

ANALYSES OF POZZUOLANA FROM FRANCE.

	1.	2.	3.	4.	5.	6.	7.
Silica (SiO_2)	47.9	47.1	46.05	48.0	35.09	30.73	38.50
Alumina (Al_2O_3)	34.2	39.0	17.0	36.4	17.65	11.63	18.35
Iron oxide (Fe_2O_3)			20.55		16.82	24.92	14.90
Lime (CaO)	8.2	7.0	8.55	8.10	4.26	3.73	8.70
Magnesia (MgO)	3.9	tr.	tr.	tr.	3.17	2.49	tr.
Alkalies (K_2O,Na_2O)	2.6	4.7	6.35	4.8	n. d.	n. d.	7.30
Water (H_2O)	3.2	2.2	1.6	2.4	19.06	19.02	7.75

1. Auvergne Mountains, black. Thorpe, Dict. App. Chem., vol. 1, p. 475.
2. " " reddish-brown. " " " " " "
3. " " brick-red. " " " " " "
4. " " Gravenvére. " " " " " "
5. Vivarais Mountains, gray. Vicat, analyst.
6. " " brown. " "
7. Department of l'Herault, brown. Vicat, analyst.

Pozzuolana has been shipped from San Miguel and Terceira in the Azores, to Portugal for over a hundred years, and has been used with very satisfactory results in many important buildings, harbor works, etc. The Azores pozzuolana varies in color from yellowish to brownish, and sometimes to grayish. It is frequently so fine-grained as not to require screening or grinding before use. A reddish colored variety from the same islands is termed tetin.

A similar ash, locally called "tosca", is obtained from Teneriffe, one of the Canary Islands, and shipped to Spain for use as a cementing material.

TABLE 236.

ANALYSES OF POZZUOLANA FROM THE AZORES ISLANDS.

	1.	2.	3.
Silica (SiO_2)	60.90	54.70	57.73
Alumina (Al_2O_3)	11.14	20.50	13.81
Iron oxide (Fe_2O_3)	12.78	6.30	12.02
Lime (CaO)	2.57	2.20	3.74
Magnesia (MgO)	1.45	1.70	1.73
Potash (K_2O)	2.64	2.20	3.21
Soda (Na_2O)	2.74		2.76
Water (H_2O)	5.78	12.40	4.66

1. From St. Miguel.—tetin. Zervas, analyst. School of Mines Quarterly, vol. 18, p. 230.
2. " " —pozzuolana. Chateau, " " " " " " "
3. " Terceira. Zervas, " " " " " " "

Volcanic materials of a type somewhat different from normal pozzuolana occur on l'Ile Bourbon, a French island lying about 400 miles east of Madagascar.

ANALYSIS OF VOLCANIC ASH, ILE BOURBON.

Silica (SiO_2)	25.67
Alumina (Al_2O_3)	16.33
Iron oxide (Fe_2O_3)	40.00
Magnesia (MgO)	tr.
Water (H_2O)	17.00

Trass.—Trass is a pale yellowish to grayish rock, rough to the feel, composed of an earthy or compact pumiceous dust mixed with fragments of pumice, trachyte, carbonized wood, etc. It is, so far as origin is concerned, an ancient volcanic mud. Trass occurs along the Rhine, in Rhenish Prussia, from Köln on the north to Coblenz on the south. The towns of Brohl, Kruft, Plaidt, and Andernach, all located northwest of Coblenz and within fifteen miles of that city, are prominent points in connection with the trass industry. A series of analyses of trass and related products is given in Table 237.

Santorin.—The island of Santorin, or Thera, is one of the most southeasterly of the islets of the Grecian Archipelago, lying in the Cyclades group. An ash called in commerce "santorin", derived from the volcano of the same name, is quite extensively shipped for use as a cementing material.

TABLE 237.

ANALYSES OF TRASS AND RELATED MATERIALS FROM GERMANY.

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	H_2O
1	46.25	20.71	5.48	2.15	1.00	6.30		9.25
2	46.6	20.6	12.0	3.0	.....	5.0		12.8
3	48.94	18.95	12.34	5.41	2.42	0.37	3.56	11.94
4	53.07	18.28	3.43	1.24	1.31	4.17	3.73	12.78
5	53.58	19.11	9.24	3.21	0.30	4.84	1.87	7.50
6	54.0	16.5	6.1	4.0	0.7	10.0		7.0
7	55.28	17.34	3.90	3.17	0.87	4.70	3.80	10.63
8	57.0	16.0	5.0	2.6	1.0	7.0	1.0	9.6
9	57.5	10.1	3.9	7.7	1.1	6.4		12.6
10	58.32	20.88	4.15	2.19	1.10	3.91	4.11	5.87
11	61.10	12.70	10.20	8.10	1.90	2.10	2.10	1.40
12	59.40	22.70	2.50	3.10	0.80	3.50	2.80	4.80
13	60.49	19.95	9.37	3.12	1.43	3.40		1.33
14	62.83	21.55	4.11	0.72	0.42	3.35	3.02	4.19
15	66.39	17.74	4.97	0.53	0.47	3.05	1.94	4.89
16	67.60	11.30	5.20	8.20	2.80	0.60	0.50	3.10

1. Trass. Rhenish. Thorpe, Dict. App. Chem., 3d ed., vol. 1, p. 475.
2. " Dutch. Thorpe, p. 475.
3. " Andernach. Thorpe, p. 475.
4. " Plaidt. von Decken, Anal. Zirkel, Lehrbuch der Petrographie, 1894, vol. 3, p. 678.
5. " " Zervas, Anal. Zervas, School of Mines Quart., vol. 18, p. 230.
6. " Andernach. Chatoney and Rivol, Anal. Zirkel, p. 678.
7. " Kruft. Mengerschausen, Anal. Zervas, p. 320.
8. " Brohl. Berthier, Anal. Gillmore, Limes, Cements, and Mortars, p. 125.
9. " Andernach. Chatoney and Rivol, Anal. Zirkel, p. 678.
10. " Brohl. Bruhus, Anal. Zirkel, p. 678.
11. " " Kyll, Anal. Zervas, p. 320.
12. Trachyte tuff. Siebengebirge, Kyll, Anal. Zervas, p. 320.
13. " " Laacher See. Merrill, Rocks, Rock Weathering and Soils, p. 141.
14. " " Siebengebirge. Bischof, Anal. Zirkel, p. 675.
15. " " " von der Marck, Anal. Zirkel, p. 675.
16. Leucite tuff. Weibern. Kyll, Anal. Zervas, p. 320.

TABLE 238.

ANALYSES OF SANTORIN ASH, FROM SANTORIN.

	1.	2.	3.	4.
Silica (SiO_2)................	72.84	71.44	63.07	66.37
Alumina (Al_2O_3)............	12.26	9.87	15.67	13.72
Iron oxide (Fe_2O_3)...........	4.35	3.84	8.73	4.31
Lime (CaO)................	2.55	2.64	3.83	2.98
Magnesia (MgO).............	1.58	1.84	1.93	1.29
Potash (K_2O)...............	1.28	1.86	1.87	2.83
Soda (Na_2O)................	2.65	3.74	3.86	4.22
Water (H_2O)...............	2.25	4.61	1.14	4.06

1. Pumiceous portion. Feichtinger, analyst. Thorpe, Dict. App. Chem., vol. 1, p. 476.
2. Fine ash. " " " " " " " "
3. Obsidian particles. " " " " " " " "
4. Average sample. " " School of Mines Quarterly, vol. 18, p. 230.

Arênes, etc.—The materials called "arênes" by early French writers on cement technology are sands and residual material derived from the decay of various igneous rocks, and particularly from the decay of the more basic rocks, such as trap, basalt, etc. Such materials will naturally vary greatly in composition and properties, but all of them agree in possessing feeble hydraulicity. For present-day commercial purposes they are practically worthless.

TABLE 239.

ANALYSES OF ARÊNES, FRANCE.

	1.	2.	3.	4.	5.
Silica (SiO_2)	38.54	60.33	42.10	38.50	60.30
Alumina (Al_2O_3)	20.00	21.43	23.65	29.40	23.70
Iron oxide (Fe_2O_3)	12.00	8.57	22.47	18.10	10.30
Lime (CaO)	8.00[1]	6.69	tr.	2.00	tr.
Magnesia (MgO)	n. d.		.....	.....	2.50
Alkalies (K_2O,Na_2O)	n. d.	n. d.	1.28	1.50	3.20

[1] Lime carbonate ($CaCO_3$).

1. Saint Astier, Department Dordogne. Vicat, analyst.
2. Brest. Vicat, analyst.
3. Saint Servan. Vicat, analyst.
4. " " " "
5. Chateaulin. " "

As might be inferred from the examples given, natural materials showing slightly hydraulic properties are not of rare occurrence. With the exception of trass, santorin and pozzuolana proper, these materials are rarely sufficiently hydraulic to be of service as bases for puzzolan cements or mortars. The feebly hydraulic materials have, however, a practical value which may be noted briefly here. It is—that, owing to the fact that they are hydraulic, they can be profitably substituted in places where they occur for common sand in mortar.

Chelius has tested * the fine material remaining after the crushing of basalt in an ordinary stone-crusher. This fine material (dust and screenings) gave the following results as compared with normal sand:

TABLE 240.

STRENGTH OF BASALTIC DUST.

	Tension.			Compression.		
	28 Days.	90 Days.	1 Year.	28 Days.	90 Days.	1 Year.
Cement and normal sand	...	20.9	....	....	237.7	
Cement and basalt fines	...	43.6	....	....	320.8	
Lime and normal sand	6.3	....	8.5	14.2	....	35.8
Lime and basalt fines	7.7	....	11.1	44.9	....	67.8

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* Journ. Soc. Chem. Ind., vol. 19, p. 826.

Part of the superiority, as shown by these tests, of the basalt dust to normal sand is probably due to purely physical causes. In part, however, it is probably due to the fact that the finely crushed basalt acted as a puzzolanic material.

Range and average composition of natural puzzolanic materials.—From the separate tables of analyses given in preceding paragraphs the following table of average analyses have been prepared:

TABLE 241.

AVERAGE ANALYSES OF NATURAL PUZZOLANIC MATERIALS.

	Pozzuolana, Italy.	Pozzuolana, France.	Pozzuolana, Azores.	Trass, Germany.	Santorin.	Average Natural Puzzolanic Material.
Number of analyses	9	7	3	11	1	31
Silica (SiO_2)	50.98	41.91	57.78	53.78	66.37	51.08
Alumina (Al_2O_3)	15.55	16.16	15.15	17.38	13.72	16.30
Iron oxide (Fe_2O_3)	14.41	19.30	10.37	6.89	4.31	11.13
Lime (CaO)	7.39	6.93	2.84	3.89	2.98	5.46
Magnesia (MgO)	1.96	1.37	1.63	1.17	1.29	1.50
Alkalies (K_2O,Na_2O)	6.63	5.15	4.52	6.82	7.05	6.21
Water (H_2O)	5.09	7.89	7.61	9.22	4.06	7.64

Puzzolanic materials in the United States.—Volcanic ash and other materials which may be expected to show puzzolanic action occur extensively in the western United States, but few tests appear to have been made of their hydraulic properties.

Mr. J. S. Diller, in a recent description* of the mineral resources of the Redding district of California, has noted that a "tuff, bordering the northern end of the Sacramento Valley, is very like the trass of the Rhine Valley. This is especially true of that on Stillwater, near the Copper City road, or east of Millville, and at a number of points on the western side of the Sacramento Valley. The limestone and the tuff are at several places within a few miles of each other, and there is reason to believe that a good quantity of hydraulic cement may be made from them within convenient reach of the railroad. This matter is of importance in the construction of large dams for irrigation or water-power in the Redding region. Similar volcanic products occur in Arizona, and have been used locally as puzzolanic materials.

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* Bulletin 225, U. S. Geological Survey, p. 177, 1904.

Artificial Puzzolanic Materials.

Blast-furnace slag is by far the most prominent of the artificial puzzolanic materials. Other artificial materials have, however, been used for this purpose, burnt clay being one of the better known of these minor products.

Burnt clay.—The following recent note * is of interest in the present connection.

"Mortar composed of lime and burnt clay was used extensively in constructing the Asyût Barrage completed in 1902, across the Nile, and described in detail in a paper by Mr. George Henry Stephens, M. Inst. C. E., to the institution of Civil Engineers on March 15, 1904. After being burnt the clay was ground and passed through a 100-mesh sieve. The best results were had with a clay burnt to a light terra-cotta color as compared with clay burned brick-red and clay burned dark red to purple. The ground clay was mixed with slaked lime and sand was added to form a mortar. The following are the results of long-time tensile tests made with various mixtures moulded into standard briquettes kept in water after 12 hours in air":

TABLE 242.

STRENGTH OF LIME—BURNT-CLAY MORTARS.

Mixture by Volume.	Age 1 Year.	Pounds per Square Inch.	Age 2 Years.	Pounds per Square Inch.
3 clay 2 lime	Maximum	400	Maximum	410
	Average of 52 samples	272	Average of 56 samples	320
1 clay 1 lime	Maximum	305	Maximum	350
	Average of 38 samples	239	Average of 25 samples	291
¾ clay 1 lime ¾ sand	Maximum	320	Maximum	376
	Average of 37 samples	259	Average of 55 samples	280

Blast-furnace slags.—Slags, according to the general use of that term, are the fusible silicates formed during metallurgical operations by the combination of the fluxing materials with the gangue of the ore. The composition of the slag, therefore, depends upon the character and relative proportions of the gangue and the fluxes. The slag will, in general, contain only those elements present in either gangue or flux; though it may contain also a percentage, usually small, of the metal which is being reduced, and its composition may, in some processes,

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* Engineering News, vol. 53, p. 177. Feb. 16, 1905.

be slightly modified by the presence of the elements taken up from the fuel. The slags or "cinders" obtained in refining the metals differ from the normal slags in that they may contain a very appreciable percentage of metal, sufficient in many cases to justify further treatment of the slag in order to recover its metallic contents. As this utilization of such slags is entirely a metallurgical operation, they will not be further discussed in the present volume.

While many elements may occur in slags, those which are of universal or even common occurrence are relatively few. The slags most commonly formed are silicates, consisting essentially of silica, oxides of the alkaline elements, and certain metallic oxides, these last, with the exception of alumina, being usually present in small quantity only. In certain metallurgical operations, however, the percentage of metallic oxides may rise so as to make them important ingredients in the slag. According to the processes, ores or fluxes used, slags may also contain more or less phosphoric anhydride, sulphur and fluorine.

The particular use, or uses to which the slag from any given furnace may be most profitably put, will depend upon several factors. When considering possible utilizations, the most important factor will generally be found to be the chemical composition of the slag. It is true that, for certain uses, as for example highway macadam and railroad ballast, the physical condition of the slag is of rather more importance than its chemical composition; but the two utilizations named are among the less profitable, and are only to be considered when the slag cannot be disposed of more profitably. Local conditions, under which head may be grouped questions of furnace management, possible markets, and transportation routes and charges, will be found to be of great economic importance. These factors are, however, too variable to be discussed in the present volume, with one exception. The exception noted is the effect of slag utilization upon the general furnace management. The furnace manager who is endeavoring to profitably utilize his slag will often find it necessary to consider how far he may economically go in changing details of his main process in order to increase the value of his by-product. This is particularly the case where the slag is used for cement.

Blast-furnace slags of certain types have been used extensively in Europe, and to a less extent in the United States, in the manufacture of slag cement. The following chapters will therefore be devoted to a discussion of the materials, manufacture and properties of slag cements.

CHAPTER XLII.

SLAG CEMENT. REQUISITES AND TREATMENT OF THE SLAG.

Slag cement is at present by far the most important member of the group of puzzolan cements, so that its manufacture will be described in some detail.

Summary of general methods of manufacture.—Slag cement is composed of an intimate mechanical mixture of slaked lime and granulated blast-furnace slag of suitable chemical composition; both materials being finely pulverized before, during or after mixing. The process of manufacture includes the granulating and drying of the slag, the slaking of the lime, the mixing of these materials, and the grinding of the resulting cement, together with any means which may be employed for the regulation of the setting time of the cement.

These different factors in the manufacture will be described in the order named above. In the present chapter, the character and treatment of the slag will be taken up.

Composition of the Slag.

Requisite chemical composition of slag.—The slag used in cement-manufacture must be a basic blast-furnace slag. Tetmajer, the first investigator of slag cements, announced as the results of his experiments (*a*) that the hydraulic properties of the slag increased with the proportion of lime contained in it, and that slags in which the ratio $\frac{CaO}{SiO_2}$ was so low as to approach unity were valueless for cement-manufacture; (*b*) that, so far as the alumina content of the slag was concerned, the best results were obtained when the ratio $\frac{Al_2O_3}{SiO_2}$ gave a value of 0.45 to 0.50; and (*c*) that with any large increase of alumina above the amount indicated by this value of the alumina-silica ratio, the tendency of the cement to crack (when used in air) was increased.

Prost, at a later date, investigated the subject, using for experiment several commercial slags and also a series prepared from pure CaO, SiO_2, and Al_2O_3. He decided that the hydraulic properties (both as regards rapidity of set and ultimate strength) of the slag increased as the proportions of lime and alumina increased; and failed to find any indication that a high alumina content causes disintegration. His best results were obtained from slags having the compositions respectively of $2SiO_2$, Al_2O_3, $3CaO$, and $2SiO_2$, Al_2O_3, $4CaO$.

Mahon, in 1893, made a series of experiments to determine the value (for cement-manufacture) of a large series of the slags produced by the furnaces of the Maryland Steel Company: and found that the slags giving the best results were two having respectively the following compositions:

(1) SiO_2, 30%; Al_2O_3, 17%; CaO, 47.5%; S, 2.38%; and (2) SiO_2, 25.3%; Al_2O_3, 20.1%; CaO, 48%; MgO, 3.28%; S, 2.63%.

The ratios of $\frac{CaO}{SiO_2}$ and $\frac{Al_2O_3}{SiO_2}$, calculated for these slags are:

(1) $\frac{CaO}{SiO_2}=1.58$; $\frac{Al_2O_3}{SiO_2}=0.57$; and (2) $\frac{CaO}{SiO_2}=1.9$; $\frac{Al_2O_3}{SiO_2}=0.79$.

At the close of the experiments Mahon recommended that slags be used slightly higher in alumina than those above quoted.

Composition of slags actually used.—The specifications under which slag from the furnaces is accepted by the cement department of the Illinois Steel Company are:

(1) Slag must analyze within the following limits:

$SiO_2+Al_2O_3$ not over 49%; Al_2O_3, from 13 to 16%; MgO, under 4%.

(2) Slag must be made in a hot furnace and must be of a light-gray color.

(3) Slag must be thoroughly disintegrated by the action of a large stream of cold water directed against it with considerable force. This contact should be made as near the furnace as is possible.

A series of over 300 analyses of slags used by this company in their slag (puzzolan) cement, show the following range in composition:

SiO_2, 29.60 to 35.60%; Al_2O_3, and Fe_2O_3, 12.80 to 16.80%; CaO, 47.99 to 50.48%; MgO, 2.09 to 2.81%.

The requirements of the Birmingham Cement Company as to the chemical composition of the slags used for cement are: that the lime content shall not be less than 47.9 per cent; that the silica and lime together shall approximately amount to 81 per cent; and that the alumina and iron oxide together shall equal from 12 to 15 per cent.

TABLE 243.

ANALYSES OF SLAGS USED FOR SLAG CEMENT.

Components.	Middlesboro, England.		Harzb'g, Germany (used at Brunswick).	Belgium.	Bilbao, Spain.		Choindez, Switzerland.		
SiO_2...	30.00	31.50	30.72	32.51	32.90	38.00	26.88	27.33	26.24
Al_2O_3 .	28.00	18.56	16.40	13.19	13.25	10.00	24.12	23.81	24.74
FeO...	0.75	.....	0.43	0.48	0.46	.....	0.44	0.63	0.49
CaO . .	32.75	42.22	48.59	44.75	47.30	46.00	45.11	45.83	46.83
MgO. .	5.25	3.18	1.28	2.20	1.37	.....	1.09	0.92	0.88
CaS. ..	1.90	.....	2.16	4.90	3.42	.....	1.80	1.34	0.59
$CaSO_4$	.....	.....	.....	.....	.....	.....	.....	0.17	0.32
SO_2...	.....	0.45							
S.	.....	2.21							
MnO_2 .	0.60	0.44	tr.	0.60	1.13	.....	0.50		
$\frac{CaO}{SiO_2}$	1.09	1.34	1.58	1.37	1.44	1.21	1.68	1.67	1.78
$\frac{Al_2O_3}{SiO_2}$	0.93	0.59	0.53	0.43	0.41	0.27	0.89	0.87	0.93

Components.	Saulnes, France.		Marnaval (used at Donjeux).		Pont-a-Mousson.	Chicago, Ill.			
SiO_2 . .	31.65	31.50	28.35	28.00	32.00	32.20	33.10	31.80	34.30
Al_2O_3 .	17.00	16.62	18.15	19.5	22.0	15.50	12.60	14.80	14.76
FeO . .	0.65	0.62	1.50	....	4.00 + MgO				
CaO . .	47.20	46.10	47.40	45.0	42.00	48.14	49.98	49.74	48.11
MgO. .	1.36	.....	2.45	.....	See FeO	2.27	2.45	2.29	2.66
S.	.....	.....	1.40						
MnO_2 .	0.85								
$\frac{CaO}{SiO_2}$	1.49	1.46	1.67	1.61	1.31	1.49	1.51	1.56	1.40
$\frac{Al_2O_3}{SiO_2}$	0.53	0.52	0.64	0.69	0.68	0.48	0.38	0.46	0.43

Analyses of a number of slags used in slag-cement manufacture are shown in Table 243. The analyses of foreign slags are quoted from various reliable authorities and the analyses of the Illinois Steel Company slags have been selected from a large series published in the report of the U. S. Army Board of Engineers to show the extreme ranges of the different elements. The ratios $\frac{CaO}{SiO_2}$ and $\frac{Al_2O_3}{SiO_2}$ have been calculated for each slag and are shown in this table.

From these data it can be seen that the ratio of alumina to silica is carried very high at Choindez, and is rather low at Chicago, relatively to most of the European plants. It must be remembered, however, that one reason for carrying a high alumina-silica ratio does not apply at Chicago, as there rapidity of set is gained by the use of the Whiting process. Taking these two plants as representative of the best European and American practice, the average of the analyses given shows the ratios actually used to be: Choindez, Switzerland, $\frac{CaO}{SiO_2}=1.71$, $\frac{Al_2O_3}{SiO_2}=0.90$; and Chicago, Ill., $\frac{CaO}{SiO_2}=1.49$, $\frac{Al_2O_3}{SiO_2}=0.44$.

These results may be compared with the theoretical ratios advised by Tetmajer, Prost, and Mahon, and discussed on a previous page of the present Chapter.

Selection of slags.—The erection of a slag-cement plant in connection with any given furnace is not justified, unless a sufficient amount of the slags usually produced will fall within slag-cement requirements, as these requirements have been outlined above in the section on chemical composition of the slag. In a large plant it will usually be easy to secure a constant supply of slag of proper composition without interfering with the proper running of the furnaces. In a small plant, however, or in one running on a number of different ores, such a supply may be difficult to obtain. These points, of course, should be settled in advance of the erection of the cement-plant.

In the case of any given furnace running on ores and fluxes, which are fairly steady in composition and proportions, the selection of the slag used for cement-making may be largely based on its color, checked if necessary by rapid determinations of lime. The darker-colored slags are generally richest in lime, except when the depth of color is due to the presence of iron; the lighter-colored slags are usually higher in silica and alumina. Candlot states further* in this connection that the slag issuing at the commencement and toward the end of a discharge should be rejected because of the air-chilling which attends its slow movement.

Granulating the Slag: Methods and Effects.

Assuming that a slag of proper composition has been selected, the first step in the actual manufacture of slag cement will be the "granulation" of the molten slag. Granulation is the effect produced by bringing molten slag into contact with a sufficient amount of cold water. The physical effect of this proceeding is to cause the slag to break up into porous particles ("slag sand"). Granulation has also certain chemical effects, highly important from an economic point of view, which will be discussed later.

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* Ciments et chaux hydrauliques.

Methods of granulating the slag.—The success of the granulation depends on bringing the slag into contact with the water as soon as possible after it has left the furnace. The effects of the process will be found to vary with, (*a*) the temperature of the slag at the point of contact; (*b*) the temperature of the water; (*c*) the amount of water used, and (*d*) its method of application.

Taking up the last point first it may be noted that two general methods of application of the water have been used. In the first method the stream of slag, as it issued from the furnaces, was struck by a jet of steam under pressure. This method, which was used at one time in slag-cement plants in the Middlesboro district, England, had the effect of blowing the slag into fine threads with attached globules. It is, in fact, much the same as the process still used in the manufacture of mineral wool. From an economic point of view it had the distinct advantage of putting the slag in a condition in which it was easily pulverized by the grinding-machinery; but it had certain inconveniences, and has been almost or entirely superseded by the method now to be mentioned.

The second way in which the water may be applied is to allow the stream of slag as it issues from the furnace to fall into a trough containing a rapidly flowing stream of cold water. Care must be taken that the fall into the trough is not too great, and that the stream of water is deep enough and fast enough, for otherwise the slag will acquire sufficient momentum in its fall to solidify in a mass on the bottom of the trough. This method is in use at all slag-cement plants of the present day, being occasionally modified by the use (either in addition to or in place of the flowing stream of water in the trough) of a jet of water playing on the slag before it strikes the trough.

The following two examples, taken from present-day practice at American slag-cement plants, will serve to indicate two methods, differing in minor details only, of slag granulation.

At the first plant the furnaces are located on an embankment about 8 feet above and 20 feet away from a standard gauge-switch track. A rectangular trench about 1 foot in width is dug from the furnace to near the edge of the embankment. Here a section of semicircular sheet-iron troughing, 12 to 15 inches in diameter and about 10 feet in length, meets the trench. The inner end of the trough is fixed, and is at such a level that the bottom of the trough is about 6 inches below the bottom of the trench. The outer end of the trough is free and supported by wire ropes so that it can be readily swung into position over a box car on the switch track below.

As already noted, the bottom of the earthen trench is about 6 inches above the bottom of the iron trough. This is done to allow the insertion at this end of the trough of a 3-inch water-pipe. Slag from the furnace flows through the trench and into the trough, which is set at an inclination of about 1 inch in 10. Water is injected through the 3-inch pipe, under 10 or 15 feet head, into the trough. If enough water is used, the slag will be granulated as soon as it enters the trough, and will be readily carried down it into the car below, rarely flowing with a greater depth than 6 inches in the trough. If insufficient water is used the slag puffs up and fills the trough, so that the slag-mass has to be broken into with an iron rod and pushed along. The car into which the slag flows is provided with four 3-inch holes in its sides, to allow the surplus water to escape.

At another slag-cement plant recently visited by the writer, the granulated slag is caught in cylindrical masonry tanks, 15 feet in diameter and 10 feet in depth. The stream of molten slag flows from the furnace to and over the edge of the tank and through a semi-circular trough about 10 inches in diameter, which enters the tank at its top rim and projects 6 inches over the edge. About 6 inches below the bottom of this trough a pipe, carrying cold water under slight pressure, enters the tank, projecting into it for 4 inches. This pipe is 3 inches in diameter for most of its length, but the portion projecting into the tank is flattened so as to give an orifice 4 or 5 inches wide and about half an inch high. The stream of slag, flowing slowly along the trough and over the edge of the tank, is struck by the jet of cold water from the pipe, and is granulated. The granulated slag is taken from the tank by bucket elevators running continuously.

Effects of granulating the slag—The physical effect of causing hot slag to come in contact with cold water is to break the slag up into small porous particles. As this materially aids in pulverizing the slag, it is probable that granulation would be practiced on this account alone. But as a matter of fact, granulation has in addition to its purely physical result two important chemical effects. One is to make the slag, if it be of suitable chemical composition, energetically hydraulic; the other is to remove a portion of the sulphides contained in the slag in the form of hydrogen disulphide.

Le Chatelier states that the hydraulic properties of granulated slag are due to the presence of a silico-alumino ferrite of calcium corresponding in composition to the formula $3CaO, Al_2O_3, 2SiO_2$. This compound appears also in Portland cements, but in them it is entirely inert, owing to the slow cooling it has undergone. When, however, as in the case of granulated slags, it is cooled with great suddenness, it becomes an important hydraulic agent. When so cooled "it is attackable by weak acids and also by alkalies. It combines particularly with hydrated lime in setting, and gives rise to silicates and aluminates of lime identical with those which are formed by entirely different reactions during the setting of Portland cement. It is upon this property that the manufacture of slag cements, which assumes daily greater importance, is based".

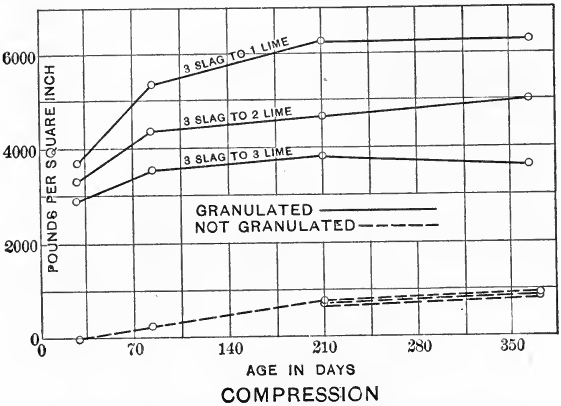

FIG. 159.*—Effect of granulating slag. (Tetmajer.)

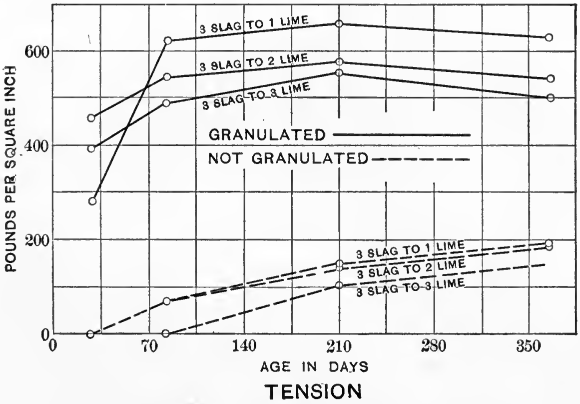

FIG. 160.*—Effect of granulating slag. (Tetmajer.)

Increased hydraulicity due to granulation.—The striking increase in the hydraulic properties of the slag when it is granulated was well brought out by Prost's investigations. The following table (244), giving the results of tests of tensile and compressive strength of briquettes of

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* From Johnson's "Materials of Construction", p. 190.

both granulated and ungranulated slag, as determined by Prost, is of interest in this connection. The results of other tests, by Tetmajer, are shown diagrammatically in Figs. 159 and 160.

TABLE 244.

STRENGTH OF GRANULATED AND UNGRANULATED SLAG. (PROST.)

Proportions of Mixture by Weight.	Resistance in Kilograms per Square Centimeter.							
	28 Days.		84 Days.		210 Days.		360 Days.	
	Tension.	Compression.	Tension.	Compression.	Tension.	Compression.	Tension.	Compression.
33 parts lime, 100 parts slag:								
Granulated	33.7	259.9	43.5	377.5	46.4	440.5	44.4	438.7
Not granulated	0	0	5.4	0	10.7	50.5	13.8	59.9
66 parts lime, 100 parts slag:								
Granulated	32.1	233.7	38.1	308.2	40.5	326.7	35.3	350.9
Not granulated	0	0	5.4	0	10.5	54.1	13.3	62.4
100 parts lime, 100 parts slag:								
Granulated	27.6	205.2	34.3	248.9	38.9	267.8	38.1	253.1
Not granulated	0	0	0	0	7.6	47.6	10.8	63.8

Desulphurization due to granulation.—When molten slag is poured into water, a very large proportion of the sulphur contained in the slag is carried off by the water. The extent to which the desulphurizing of the slag is secured by the simple method of granulating is shown by the following result from actual practice at the slag brick works at Kralovedvoor, Bohemia. Here the slag is granulated, just as in slag-cement works, by running it into flowing cold water. Examination * of the water used showed that it had increased in temperature from 14½° C. to about 56° C., and that it carried in 10,000 parts the following parts of mineral matter in solution:

SiO_2	0.426
$CaSO_4$	0.749
$FeSO_4$	0.108
$MgSO_4$	0.448
Na_2SO_4	0.178
$NaCl$	0.038
Na_2SiO_2	0.693
CaS	0.271
H_2S	0.047
	2.958

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* Engineering and Mining Journal, April 16, 1898.

Drying the Slag.

The slag as it is brought to the cement mill from the granulating tanks carries from 15 to over 40 per cent of water absorbed during granulation. As will be noted later attempts have been made to utilize this contained water in the slaking of the lime, but these attempts have hitherto proved unsuccessful. As the manufacture is at present conducted, therefore, the large percentage of water carried by the slag is of no service, and in order to get good results from the grinding machinery the water must be removed as completely as possible before pulverization is attempted.

Before describing the various types of driers in use, a few words on the general problem may be serviceable. The slag may carry, as above noted, from 15 to over 40 per cent of water, varying with the method of granulation, the fineness of grain, etc. In test runs slag can be thoroughly granulated without the use of more than 10 to 15 per cent of water, but in actual practice it will usually be found that the granulated slag carries from 30 to 45 per cent. As the slag must be reduced to extreme fineness it is necessary that this moisture be reduced as much as possible. With a well-conducted rotary drier it is possible to economically reduce the percentage of moisture in the dried product to about one-fourth of one per cent.

The temperature to which the product is carried in drying is not a matter of serious moment so long as it does not pass the point at which the slag begins to re-fuse. Theoretically, of course, it is necessary only to carry the temperature above 212° F., but in practice it is economically impossible to keep it as low as this. It may be carried as high as a dull-red heat without injury to the slag. Indeed, it is probably the case that drying at relatively high temperatures improves the hydraulic properties of the slag, rather than otherwise, as it is well known that the natural puzzolanic materials are improved by roasting. It would not, therefore, be a matter of surprise if drying the slag at a higher temperature than is actually necessary should result in materially accelerating the set of the resulting cement and also in increasing the strength of briquettes made from it.

The Ruggles-Coles drier (see Fig. 161) consists of two concentric hollow cylinders bolted together and revolving on an axis slightly inclined from the horizontal. The outside cylinder is made of steel plates, the longitudinal seams having butt joints with inside lapping straps. The inner cylinder, which is also made of steel, is connected with the outer cylinder at its middle by heavy cast-iron arms *A* solidly riveted to both cylinders, while the cylinders are further connected at each end by two sets of adjustable or swinging arms *B*, which prevent the joints being affected by the expansion or contraction of the cylinders. At the head or upper end the inner cylinder projects beyond the outer cylinder, passing into a stationary head or air chamber *E* to the hot air flue *D* of the furnace *G* with which it is connected. At the lower or discharge end is another stationary head *E* forming an air chamber, through an opening in the bottom of which the dried material is discharged. This head is supplied with a damper to regulate the temperature, which gives perfect control.

The cylinders are set at an inclination of about $\frac{3}{8}$ inch to the foot. The outer cylinder is secured to two heavy rolled steel-bearing rings,

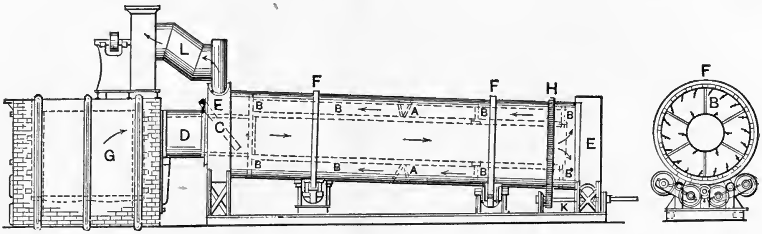

FIG. 161.—Ruggles-Coles drier.

which rest and revolve upon eight bearing wheels supported by oscillating arms or rockers. The lateral motion of the cylinder is taken up by four thrust wheels. The drier is revolved by a cast gear *H* secured to the outer cylinder, and this is driven by a shaft and pinion *K* extended beyond the end of the machine and supported in two babbitted journal boxes fitted to the frame. The entire machine is fitted and secured to a heavy frame of 8-inch I beams braced and framed together and usually set on a concrete foundation. The exhaust fan is placed where most convenient to drive, and is connected with the outer cylinder by a suitable flue *L*. The furnace *G* is built independent of the rest of the drier, and is connected with the head end of the inner cylinder by an iron flue *D* built with fire-brick. A specially designed burner is substituted for the furnace when oil, gas, or powdered coal are to be used.

The heated air passes through the inner cylinder (which is shown by the dotted lines in the illustration) and returns, between the inner and outer cylinders, to the fan. The direction of the hot-air current is shown by arrows. The wet raw material is fed into the space between the inner and outer cylinders through a spout *C* in the stationary head at the upper end of the drier. The material is picked up by buckets or carriers fastened to the inner surface of the outer cylinder, and is carried partly around during the rotation of the drier. On dropping from these buckets it is caught by flights fastened to the outer surface of the inner cylinder. These flights carry the material partly around and then drop it on the outer cylinder, when the cycle of operations commences again. While the movements of the material are occurring, it is being dried both by the heated-air current which flows through the space between the two cylinders, and by contact with the warm outer surface of the inner cylinder; and it is also being carried slowly toward the lower or discharge end of the machine.

The following table shows working results obtained in the use of the Ruggles-Coles drier on blast-furnace slag at various slag-cement plants:

TABLE 245.

WORKING RESULTS OF RUGGLES-COLES DRIER.

User.	Number of Driers.	Original Percentage Moisture.	Final Percentage Moisture.	Water Evaporated per Hour.
Knickerbocker Cement Co.	1	41.82	0.29	4401 Lbs.
Maryland Cement Co.	2	20.32	0.25	4114 "
Birmingham Cement Co. . .	2	45	. . . .	4181 "
Southern Cement Co.	2	40	. . . .	4707 "
Stewart Cement Co.	3	12.85	. . . .	2272 "

User.	Dry Material Delivered per Hour.	Coal Used per Hour.	Water Evaporated per Pound of Coal.
Knickerbocker Cement Co.	6,399 Lbs.	560 Lbs.	7.87 Lbs.
Maryland Cement Co.	16,173 "	542 "	7.59 "
Birmingham Cement Co.	4,987 "	537 "	7.60 "
Southern Cement Co.	7,061 "	550 "	8.56 "
Stewart Cement Co.	15,408 "	334 "	6.80 "

The Holst drier is used at Donjeux and Mallstadt, and consists essentially of a sheet-iron cylinder 9 meters long and 0.8 meter in diameter, into which the slag is fed automatically by a screw feed. In the cylinder a helical screw revolves on a hollow central shaft, causing the slag to advance slowly through the cylinder. The fireplace is below and near one end of the cylinder and the heat is caused to pass under the cylinder to the other end, thence through the hollow shaft to the stack in a direction contrary to that in which the slag is moving. The cylinder is protected from the direct flame by brickwork. This apparatus dries from 7 to 8 metric tons of slag per day with a coal consumption of about 5 per cent of the weight of slag dried.

At Vitry, France, a simple and effective non-rotary drier, operated by gravity, is employed, plan and section of which is given in Fig. 162. It consists of drying compartments (each of which is lettered, *a*, *b*, *c*, *d*, in the plan), arranged about a central flue (*c*, *d*, *c*, *d* in plan), through which passes the heated gases from a furnace. The central flue is 1 m. square; the drying compartments 0.5×1 m. in area, and both are 7 m. in height. Each of the drying compartments contains 10 sheet-iron plates (of which only six, E, are shown in each compartment of the section). These plates are inclined and so arranged that the wet slag, shoveled in at the top of each compartment, descends by gravity and finally issues from the lowest plate in the heaps F, from which it is shoveled and sent to the grinding mills. According to Prost, a drier of this type and size will dry from 12 to 15 metric tons of slag per working day. From 6 to 6.5 lbs. of coke are necessary to dry each 100 lbs. of slag.

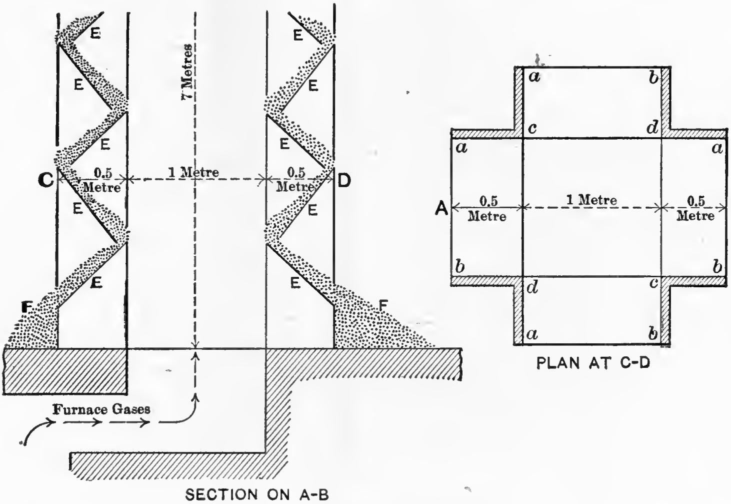

FIG. 162.—Vitry slag-drier.

Tower driers, resembling those used at one or two American Portland cement plants, could of course be used in drying slag. At present, however, every slag-cement plant in the United States uses rotary driers.

CHAPTER XLIII.

SLAG CEMENT: LIME, MIXING AND GRINDING.

After the slag has been granulated and dried, as described in the preceding chapter, it must be mixed with a carefully slaked lime, in proper proportions, and the mixture must be finely ground. These points will be taken up first in the present chapter, after which data on the general processes and costs of slag-cement manufacture will be presented.

Composition and selection of the lime.—The lime used for admixture with the slag may be either a quicklime (common lime) or a hydraulic lime. In usual American practice, and also at most European plants, a common or quicklime is used. At a few American, French, and German plants, however, limes which have more or less hydraulic properties are employed. Prost has carried on experiments touching this point and decided that the use of a hydraulic lime did not noticeably increase the tensile strength of the resulting cement, but that it did increase the value of the product in another way. This incidental advantage is that slag cements made by using hydraulic lime are less liable to fissure and disintegrate when used in air or in dry situations than cement in which common quicklime is used. As above noted, this method of improving the product has been tried, to the writer's knowledge, at only a few of the American plants. At Königshof, Germany, the general practice at which plant is described on page 662, a somewhat hydraulic lime is used, whose analysis will serve as fairly representative of materials of this type, though most hydraulic limes would run considerably higher in silica and alumina.

Analysis of Hydraulic Lime, Königshof, Germany.

	Per Cent.
Silica (SiO_2)	12.421
Alumina (Al_2O_3)	2.620
Iron oxide (Fe_2O_3)	0.883
Manganese oxide (MnO_2)	tr.
Lime (CaO)	81.546
Magnesia (MgO)	1.751
Soda (Na_2O)	0.211
Carbon dioxide (CO_2)	0.194
Moisture (H_2O)	0.425

The following analyses are of limes used at different slag-cement plants in the United States:

TABLE 246.

ANALYSES OF LIMES USED IN AMERICAN SLAG-CEMENT PLANTS.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	3.24	3.50	1.62	10.20	0.78	1.38
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	4.26	3.92	2.62	3.60	0.52	0.62
Lime (CaO)	81.92	83.20	82.40	81.33	98.40	97.80
Magnesia (MgO)	n. d.	n. d.	n. d.	1.17	0.10	0.18

Of the analyses above tabulated, it will be seen that Nos. 1 to 4 inclusive are of the semi-hydraulic type whose value has been noted. Analyses 5 and 6, on the other hand, are representative of the very pure limes used at most slag-cement plants.

Burning the lime.—As a matter of convenience, and also to reduce freight charges, the limestone is burned near the quarry. The subject of burning the lime requires only brief mention here, as it involves no points of particular interest or novelty. Only two minor details demand notice, as affecting the value of the cement. The first is, that the lime should be burned as thoroughly as possible, for unburned lumps of limestone are absolutely valueless to the cement-manufacturer, and must be removed before mixing with the slag. The second point to be noticed is, that the lime should be shipped to the cement-plant as soon as possible after it is burned, in order to prevent any considerable proportion of it from air-slaking. Air-slaked particles, while not absolutely inert, are still of little value to the cement.

Slaking the lime.—The granulated slag as it comes to the mill from the tanks to which it is carried in granulating it carries a very large percentage of water. The amount of water carried will vary in practice at different plants between 25 and 50 per cent as limits. Early in the history of slag-cement manufacture attempts were made to utilize this surplus water. To this end the wet slag was mixed with dry unslaked lime, the expectation being that the water in the slag would serve to slake the lime. In practice, however, it was soon found that this plan was not successful. The lime was only partially—and very irregularly—slaked, and the mixture was not left in such a condition as to be economically handled by the pulverizing machinery. In present-day practice, therefore, the lime is slaked previous to being mixed with the slag.

Sieving and grinding the lime.—If lime has been thoroughly burned and carefully slaked it will all be in the form of a very fine powder, much finer than can be obtained by any economically practicable grinding-machinery. In practice, however, it will be found that after slaking the lime has not all fallen to powder, but still contains a certain proportion of hard lumps. The degree of carefulness with which the burning and slaking have been conducted may be roughly judged by observing the relative proportions of lumps and powder.

The material remaining as lumps is of three different kinds. First, and in greatest proportion, are fragments of limestone which have not been thoroughly burned in the kiln. Such unburned pieces would be inert if used in the cement. Second, part of the lumps represent fragments of limestone which have been overburned in the kiln and have, therefore, partly clinkered. This is particularly likely to happen if the limestone contained any large proportion of silica or alumina. These partly clinkered lumps, being really poor-grade natural cements, can if pulverized do no particular harm to the slag cement, but on the other hand they cannot do as much good as an equal amount of lime. The third kind of material that may be present in lump form consists of fragments of well-burned lime, which, through accident or carelessness, have not been well slaked. These lumps of quicklime would, if incorporated in the cement, be actively injurious.

The preceding description and discussion of the three classes of material which are likely to remain as lumps in the slaked lime have been intentionally made detailed in order to point out an error in practice committed occasionally at slag-cement plants. It has been seen that the materials composing these lumps are of such a character as to be either useless or actively injurious if used in a slag cement. It should be obvious, therefore, that the only rational method of treatment is to sieve the slaked lime and to reject entirely all the material failing to pass through the sieve. This is the best practice and the method usually followed. Occasionally, however, urged by a false idea of economy or by inaccurate reasoning, the manufacturer saves the material failing to pass the sieve, crushes it, and adds it to the cement at a later stage in the manufacture.

Proportions of lime and slag.—Prost, in consequence of his experiments with various proportions of lime, advocated the proportion, to secure the best results, of from 35 to 40 parts of lime to 100 parts of slag. He also stated that the amounts of lime used in actual practice, for each 100 lbs. of slag were: at Choindez, 40 to 45 lbs.; at Donjeux, 40 lbs.; at Brunswick, 33 lbs., and at Cleveland, 33 lbs. Mahon, in reporting his experiments for the Maryland Steel Company, states that the best results were secured by the use of 25 parts of lime to 100 parts of slag, by weight. At another American plant the proportions used are 20 lbs. lime to 100 lbs. slag. In the manufacture of slag brick, which is in reality merely a branch of the slag-cement industry, the amount of lime added may fall as low as 10 lbs. to 100 lbs. of slag.

These rules are, of course, purely empirical; and it is time that some better method of calculating the mixture should be presented. This of course, can be accomplished by the use of the same device which has been previously discussed in connection with hydraulic limes, natural cements, and Portland cements.

Calculating the mixture.—If we determine the Cementation Index * of a series of representative American slag cements, such as is given on page 667, we will find that the value obtained ranges from about 1.6 to 1.9

Accepting these values as fairly typical the information thus gained can be employed in devising a method for determining accurately the proportions in which any given slag should be mixed with any given lime in order to secure a good slag cement.

Operation 1. **Slag.**—Multiply the percentage of silica in the slag by 2.8, the alumina by 1.1, and the iron oxide by 0.7; add all the products together. From the sum subtract the percentage of lime in the slag plus 1.4 times the magnesia. Call the result "m".

Operation 2. **Limestone.**—Multiply the percentage of silica in the unslaked quicklime by 2.8, the alumina by 1.1, and the iron oxide by 0.7, and add the products together. Subtract this sum from the total percentage of lime (CaO) plus 1.4 times the magnesia. Call the result "n".

Operation 3. Divide $100 \times m$ by $1.7 \times n$. The quotient, $\frac{100\,m}{1.7\,n}$, will equal the number of parts of quicklime to be used for each 100 parts of slag. The factor by which n is to be multiplied is here taken as 1.7, a very satisfactory value. Values as low as 1.6 and as high as 1.9 would, however, give the proportions used in practice at various plants.

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* As previously explained in detail (pp. 170–171), the Cementation Index is the value obtained from the formula

$$\text{Cementation Index} = \frac{(2.8 \times \text{percentage silica}) + (1.1 \times \text{percentage alumina}) + (0.7 \times \text{percentage iron oxide})}{(\text{Percentage lime}) + (1.4 \times \text{percentage magnesia})}.$$

Example.—Assume that the two raw materials have the following composition:

	Slag.	Limestone
Silica (SiO_2)	32.2	1.8
Alumina (Al_2O_3)	12.0	1.2
Iron oxide (FeO, Fe_2O_3)	0.6	0.4
Lime (CaO)	48.1	94.0
Magnesia (MgO)	2.3	1.2

Operation 1. Slag.

$$\begin{array}{lrr}
\text{Silica} & \times 2.8 = 32.2 \times 2.8 = & 90.16 \\
\text{Alumina} & \times 1.1 = 12.0 \times 1.1 = & 13.20 \\
\text{Iron oxide} & \times 0.7 = 0.6 \times 0.7 = & 0.42 \\
\cline{3-3}
 & & 103.78 \\
\text{Lime} & \times 1.0 = 48.1 \times 1.0 = & 48.1 \\
\text{Magnesia} & \times 1.4 = 2.3 \times 1.4 = & 3.22 \\
\cline{3-3}
 & & 51.32
\end{array}$$

$$103.78 - 51.32 = m = 52.46$$

Operation 2. Lime.

$$\begin{array}{lrr}
\text{Silica} & \times 2.8 = 1.8 \times 2.8 = & 5.04 \\
\text{Alumina} & \times 1.1 = 1.2 \times 1.1 = & 1.32 \\
\text{Iron oxide} & \times 0.7 = 0.4 \times 0.7 = & 0.28 \\
\cline{3-3}
 & & 6.64 \\
\text{Lime} & \times 1.0 = 94.0 \times 1.0 = & 94.00 \\
\text{Magnesia} & \times 1.4 = 1.2 \times 1.4 = & 1.68 \\
\cline{3-3}
 & & 95.68
\end{array}$$

$$95.68 - 6.64 = n = 89.04$$

Operation 3.

$$\frac{100\,m}{1.7n} = \frac{100 \times 52.46}{1.7 \times 89.04} = \frac{5246}{151.4} = \left\{\begin{array}{l} 34.6 = \text{parts unslaked quicklime for each} \\ \quad \text{100 parts dry slag.} \end{array}\right.$$

Pulverizing and mixing.—The greatest differences in practice exist in the processes for grinding and mixing the slag and lime. The statement has been made in several publications that the differences in hardness between dry granulated slag and slaked lime is so great that it is impracticable to pulverize them together in a continuously operated mill. A number of plants, therefore, have installed small discontinuous mills, each of which is charged, locked, operated for a sufficient time to pulverize both constituents of the mixture, and discharged. The disadvantages of this intermittent system are obvious and it seems especially unfitted for American conditions. The statement that no continuously operated mill was able to handle the mixture seemed inherently improbable, in view of the great variety of material successfully handled by the modern ball and tube mills when operated continuously in Portland-cement practice. Several years ago I referred the question to a leading firm of manufacturers and was informed that nothing in their experience justified the unfavorable conclusion, and that their continuously operated tube mills had successfully pulverized mixtures of slag and lime. It seems probable that the most economical practice would be to send the dried slag through a small crusher, Griffin mill, or ball mill, mixing the crushed slag with lime and completing the mixture and reduction in continuously operated tube mills. Whatever system of reduction is employed, it is necessary that the slag be dried as completely as possible, and, with modern dryers, the amount of moisture in the dried slag can be economically kept well below 1 per cent.

In this connection it may be of service to note the results attained in the grinding of basic Bessemer slag (for use as a fertilizer) by the Pottstown Iron Company. A 2000-mm. Jensch ball mill was there employed. This mill consumed about 13 H.P. Its normal output was 20,000 lbs. in ten hours, though a maximum of 29,000 lbs. in ten hours had been reached on perfectly dry slag. The fineness of the product was such that 95 to 98 per cent would pass a 100-mesh sieve and 70 to 75 per cent a 150-mesh sieve. A West tube mill in use at an American slag-cement plant grinds 8½ barrels per hour of mix to a fineness of 95 per cent through 200-mesh, or 10 barrels per hour to a fineness of 90 per cent. In doing this it uses 67 H.P., equivalent to power consumption of 8 H.P. hours or 6.7 H.P. hours, respectively.

Regulation of set.—Slag cements will normally set very slowly compared to Portland cements. As this interferes with their use for certain purposes, many attempts have been made by various treatments to reduce their setting-time. There is, unfortunately, another reason why the manufacturer should desire to hasten the set of his product. Most of the slag cements sold in this country masquerade as Portland, and it is desirable to the manufacturer, therefore, to make such of their properties as are brought out in ordinary tests or analyses approximate to those of true Portland cement. The set of slag cements can be hastened by the addition of puzzolanic materials. Of these, burned clay, certain active forms of silica, and slags high in alumina are the cheapest and most generally obtainable. The most important method of regulation is, in this country at least, the Whiting process, which is followed at two large American plants.

United States Patent No. 544,706, issued in 1895 to Jasper Whiting, covers the use of "caustic soda, potash, sodium chloride, or equivalents or any substance of which the latter are ingredients", added either as aqueous solutions or in a dry state at any stage of the process of slag-cement manufacture. In the specifications accompanying the application for this patent, the patentee states that, in the case of dry caustic soda the amount added will vary from 0.125 to 3 per cent, "depending chiefly upon the use for which the cement is intended". The patent was subsequently conveyed to the Illinois Steel Company, and the process covered by it is used by that company in the manufacture of its "Steel Portland" cement. A license has been issued to the Brier Hill Iron and Coal Company, of Youngstown, Ohio, under which license this company manufactures its "Brier Hill Portland" cement.

The process, as practised in the slag-cement plant of the Illinois Steel Company, Chicago, Ill., is described as follows: The quicklime used is obtained from the calcination of Marblehead or Bedford limestone and carries less than 1 per cent MgO. On its arrival at the mill it is unloaded into bins, beneath which are placed two screens of different mesh, the coarser at the top. A quantity of lime is drawn upon the upper screen, where it is slaked by means of the addition of water containing a small percentage of caustic soda. As the lime is slaked it falls through the coarse screen onto the finest screen, through which it falls into a conveyor which carries it to a rotary drier. After heating, the resulting slaked and dried lime is carried by elevators to hoppers above the tube mills, where it is mixed in proper proportions with the granulated slag, which has been dried and powdered.

General Practice.—The general practice followed at a number of American and European slag-cement plants will now be described.

A very recent and typical installation is shown in Fig. 163, which gives the plan and elevation of the slag-cement plant of the Stewart Iron Co., at Sharon, Pa. It will be seen that the granulated slag is passed through Ruggles-Coles driers, three of which are in use, and is then elevated to a dry-slag bin on the second floor of the mill. The lime is slaked in an adjoining room, and is also elevated to the second floor. Here the two materials are fed in proper proportions to a screw conveyor, which carries them to a Broughton mixer. The mix is then conveyed to three West tube mills, which deliver the finished product. The Maryland Cement Company,* at Sparrows Point, Md., obtains the slag from the furnaces of the Maryland Steel Company. The slag is dried in Ruggles-Coles driers, and after mixing with the slaked lime

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* Lewis, F. H. Cement Industry, p. 184.

is ground in discontinuous West pebble mills. Mahon's experiments preliminary to the establishment of this plant are discussed on an earlier page.

The slag-cement plant of the Illinois Steel Company, Chicago, Ill., obtains its slag from the blast-furnaces of that company. The specifications under which this slag is received, with analyses showing its actual range in composition, will be found on a previous page. After granulation and drying in a specially designed dryer the slag receives its preliminary reduction in Griffin mills. Meanwhile the lime has been slaked as described in detail on a previous page (p. 659), caustic soda being added to regulate the set of the product. The ground slag and

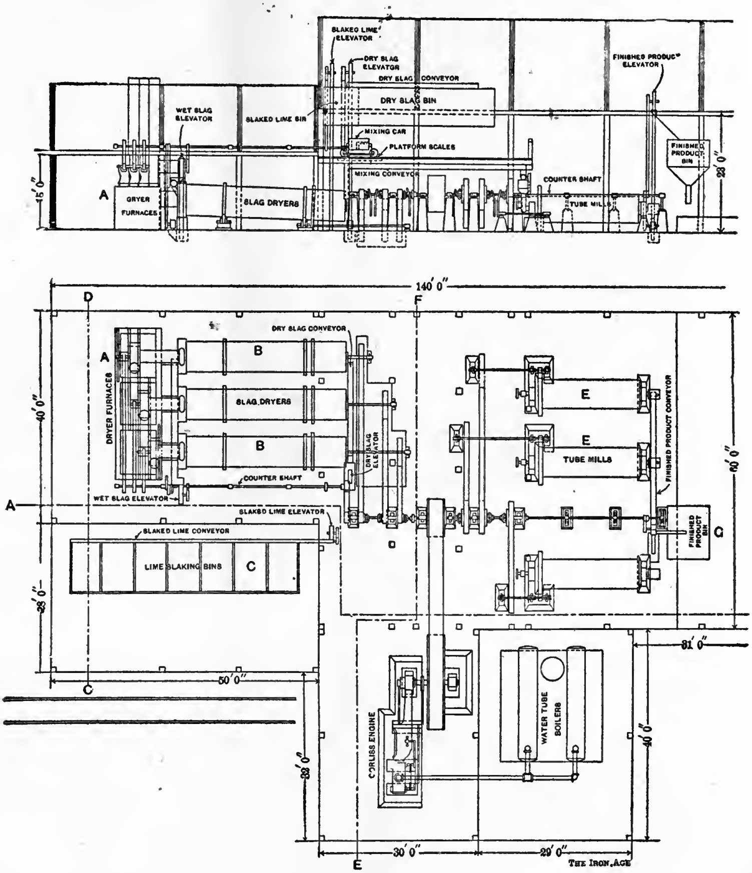

FIG. 163.—Elevation and plan of Stewart slag-cement plant. (The Iron Age.)

this prepared lime are then mixed, and the mixture receives its final reduction in Davidsen tube mills.

At the plant of the Birmingham Cement Company,* at Ensley, Ala., slag is obtained from the furnaces of the Tennessee Coal and Iron Company, located in near-by towns. The slag is granulated at the furnaces. On arrival at the mills, carrying about 40 per cent of water, it is dried in Ruggles-Coles driers. Two of these, of the A2 style, are in operation. After drying, the slag and slaked lime are fed together to West ball mills, four of which are in use, and the mixture is finally reduced in West tube mills.

The Southern Cement Company, at North Birmingham, Ala., dries its slag in a style A2 Ruggles-Coles drier. The dried slag is crushed in a Kent mill. After mixing with the slaked lime, the final reduction takes place in West tube mills. Two brands of slag cement are marketed. One, a normal slag cement, is said to average about CaO 55 per cent, Fe_2O_3, Al_2O_3, 12 per cent, SiO_2, 27 per cent. The other brand is quicker setting and is said to carry about 10 per cent less CaO and about 10 per cent more SiO_2.

At Skinningrove, England, slags were used of a composition varying between the following limits: SiO_2, 30 to 32 per cent; CaO, 30 to 33 per cent; Al_2O_3, Fe_2O_3, 25 to 28 per cent. The slag on issuing from the furnace was run into water; ground, before drying, under edge runners, and dried on iron plates in a drying chamber. The dried material was ground under millstones; sieved, and mixed with lime (which had been slaked and screened) in the proportions usually of lime 33 lbs., slag 100 lbs. The resulting cement varied in composition between the following limits: SiO_2, 24 to 26 per cent; CaO, 45 to 47 per cent; Al_2O_3, Fe_2O_3, 20 to 22 per cent.

At Vitry, France, the slag is struck by a jet of water immediately upon issuing from the furnace and carried by it into a masonry storage tank. From this tank the granulated slag is elevated and carried to the mill. Five driers of the style shown in Fig. 162 are employed, the dimensions being slightly different from those used at Choindez. After drying the slag is sieved, to remove the coarser particles, passed through six mills of different types, and again sieved. After having been thus reduced to the proper fineness, it is mixed with the slaked lime in ball mills operated discontinuously; the proportions being about 40 lbs. of lime to 100 lbs. of slag.

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* Eckel, E. C. Engineering News, Jan. 23, 1902.

The slag-cement plant at Königshof,* Germany, utilizes slag from the Carl-Emil furnaces. A typical analysis of this slag shows:

	Per Cent.
SiO_2	26.29
Al_2O_3	18.71
FeO	1.80
CaO	49.16
MgO	2.45

The more important constituents commonly vary between the following limits:

	Per Cent.
SiO_2	24 to 27
Al_2O_3	17 " 19
CaO	49 " 54

The slag is granulated, dried, and ground to such fineness that all passes a sieve with 900 meshes per square centimeter, and 85 per cent passes a sieve of 5000 meshes per square centimeter.

The limestone is obtained from quarries at Koneprus, and is burned in continuous shaft kilns. Analysis of the resulting lime shows:

	Per Cent.
SiO_2	12.421
Al_2O_3	2.620
Fe_2O_3	0.883
CaO	81.546
MgO	1.751
CO_2	0.194
Moisture	0.425

From this analysis it would seem probable that the lime is itself somewhat hydraulic. It is carefully slaked, and stored until the slaking is complete, after which it is screened to remove the coarser particles.

The slag and lime are then mixed and ground together in proportions giving a cement of the following typical composition:

	Per Cent.
SiO_2	20.81
Al_2O_3	10.50
Fe_2O_3	1.90
CaO	55.90
MgO	1.41
S	0.58
SO_3	0.91
Loss on ignition	3.50

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* Jour. Iron and Steel Inst., vol. 2, 1900, p. 508.

The specific gravity of this cement ranges between 2.80 and 2.90. In all its properties it resembles other slag cements.

Slag cement is made at the Cockerill plant * at Seraing, Belgium, from blast-furnace slags ranging within the following limits:

	Per Cent.
SiO_2	27 to 32
Al_2O_3	12 " 22
CaO	49 " 55

The slag is granulated and dried, the latter taking place at a temperature of about 500° C., and requiring a fuel (coke) consumption of about 9 per cent of the weight of slag dried. The slag is ground so as to all pass a sieve of 76 meshes to the inch, and leave a residue of only 8 to 12 per cent on a sieve of 180 meshes to the inch. Grinding to this fineness requires 25 to 30 H.P. for the production of 450 to 800 kilograms per hour of powdered slag. Lime is burned, slaked by immersion, and stored eight to ten days, at the end of which time it is screened to pass a 76-mesh sieve. It is then mixed with the slag in the proportion of 15 to 20 parts of lime to 100 parts slag.

Costs of manufacture.—Data regarding the cost of manufacture of slag cement have been recently published.† The figures quoted are said to have been the costs of actual manufacture some years ago at the plant of the Maryland Cement Company. They are as follows, being based on a production of 5000 barrels per month:

	Per Barrel.
Mill force, labor and superintendence	$0.160
125 tons of coal at $3.05 per ton	0.076
3000 bushels of lime at $0.16 per bushel	0.100
900 tons of slag at $0.50 per ton	0.090
Repairs, $100 per month	0.020
Oil and grease, $40 per month	0.007
Contingencies	0.011
	$0.464
Cost of administration	$0.121
	$0.585

These figures seems rather high in some respects. For American plants I should say that the average cost of manufacture should not be over 35 cents per barrel.

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* Eng. and Min. Jour., vol. 64, pp. 515–516.

† Boilleau and Lyon. Cost of making slag cement. Municipal Engineering, vol. 26, p. 321. May 1904.

This would be itemized about as follows:

TABLE 247.

COSTS OF SLAG-CEMENT MANUFACTURE PER BARREL.

	Min.	Max.
Slag	.04	.10
Lime	.07	.12
Coal	.03	.08
Oil, grease, waste, etc.	.005	.01
Repairs	.01	.03
Labor	.05	.08
Superintendence, testing, etc.	.03	.05
	.23½	.47

Several American plants have to my knowledge worked quite close to the minimum estimate above given. To this cost should be added, of course, interest on the cost of the plant. If the plant is running steadily this item should not amount to more than two or three cents a barrel.

Production of slag cement.—The following data on the slag cement output of the United States are taken from the volumes on mineral resources annually issued by the U. S. Geological Survey:

TABLE 248.

SLAG-CEMENT PRODUCTION IN THE UNITED STATES, 1899–1904.

Year.	Number of Plants.	Barrels.	Value.
1899	3	233,000	?
1900	5	365,611	$274,208
1901	5	272,689	198,151
1902	6	478,555	425,672
1903	7	525,896	542,502
1904	8	305,045	226,651

List of references on the manufacture of slag cement.

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CHAPTER XLIV.

SLAG CEMENTS: COMPOSITION AND PROPERTIES.

WHILE slag cements are sufficiently like Portland cements to be usually marketed as Portland, certain interesting differences between the two cements are shown on close examination.

Identification of slag cement.—Slag cements may usually be distinguished from Portland cements by their lighter color, inferior specific gravity, and slower set. They show on analysis lower lime and higher alumina percentages than Portlands and usually contain an appreciable amount of calcium sulphide. Owing to the presence of this last named constituent a briquette of slag cement left for some days in water will show upon fracture a decided greenish tint; if it has been exposed to salt water, this tint will be much more marked, and the odor of hydrogen sulphide will be observed. Two things should be noted, however, in this connection. The presence of sulphides though usual is not a necessary occurrence in slag cements; and, on the other hand, sulphides are occasionally present in Portland cements, being formed from the sulphates in case the flame of the kiln is not sufficiently oxidizing. Another chemical difference between the two types of cement is in the high "loss on ignition" shown by slag cements. This loss, which may range from 4 to 8 per cent, is due largely to the water carried by the slaked lime.

Chemical Composition of Slag Cements.

The ultimate composition of a sample of slag cement will, of course, be brought out by chemical analysis; but the fact that the material is not a chemical compound but merely a mechanical mixture will not be shown in the ordinary report of such an analysis. The average commercial chemist will, moreover,—particularly, if he be accustomed to analyzing Portland cements—make careless and erroneous statements concerning three important points. The three points noted are: (*a*) the condition of the iron which is present, (*b*) the condition of the sulphur which is present, and (*c*) the nature of the "loss on ignition".

A discussion of analytical methods will not be undertaken, as that subject does not properly belong in a treatise of this character. But it may be of value, not only to engineers and slag-cement manufacturers, but to commercial chemists, to state in some detail what substances are to be expected in examining a normal slag cement. Slag cement, when ready for sale, is a mechanical mixture of slaked lime and slag. The slaked lime is lime hydrate [$Ca_2(OH)_2$]; the slag may be regarded as a calcium aluminum silicate ($x.CaO$, $y.Al_2O_3.SiO_2$). In addition to the essential ingredients—lime, silica, alumina, and water—contained in these two components of the cement, certain other constituents may occur in small but often interesting percentages. Of these sulphur, iron, magnesia, carbon dioxide, fluorine and soda are those most commonly found.

Analyses of a number of American slag cements are presented in the following table. The Cementation Index of several of these has been calculated, and it will be seen that it gives values (1.59, 1.67, 1.72, 1.87) far above those given by any modern Portland cement:

TABLE 249.

ANALYSES OF AMERICAN SLAG CEMENTS.

	1.	2.	3.	4.	5.	6.
Silica (SiO_2)	27.78	27.20	28.40	28.95	29.80	27.80
Alumina (Al_2O_3)	11.70	14.18	12.80	11.40	12.30	11.10
Iron oxides (FeO, Fe_2O_3)				0.54		
Lime (CaO)	51.71	50.33	51.50	50.29	51.14	50.96
Magnesia (MgO)	1.39	3.22	n. d.	2.96	2.34	2.23
Sulphur (S)	1.31	0.15	1.40	1.37	1.37	1.18
Carbon dioxide (CO_2)	n. d.	4.25	n. d.	3.39	2.60	5.30
Water						
Cementation Index	1.67	....	....	1.72		

	7.	8.	9.	10.	11.	12.
Silica (SiO_2)	27.15	28.84	30.98	28.90	29.64	30.20
Alumina (Al_2O_3)	10.80	10.42	11.72	12.72	12.62	11.26
Iron oxides (FeO, Fe_2O_3)	0.90	n. d.	n. d.			
Lime (CaO)	51.57	51.81	51.07	51.19	51.17	51.81
Magnesia (MgO)	2.70	2.21	1.45	1.87	1.98	3.37
Sulphur (S)	1.38	1.42	1.22	1.07	1.13	1.30
Carbon dioxide (CO_3)	3.50	n. d.	n. d.	n. d.	n. d.	n. d.
Water						
Cementation Index	1.59	....	1.87			

1. "Southern Cross Portland". Birmingham Cement Co., Ensley, Ala. Private communication.
2. "Steel Puzzolan". Illinois Steel Co., Chicago, Ill. Lathury & Spackman, anal. Mfrs. circular.
3–6. "Steel Puzzolan". Illinois Steel Co., Chicago, Ill.
7. Maryland Cement Co., Sparrows Pt., Md. Cement Directory, 2d ed., p. 207.
8. " " " " " " Private communication.
9. "Brier Hill Portland". Brier Hill Coal & Iron Co., Brier Hill, Ohio. Private communication.
10–12. "Stewart Portland". Stewart Portland Cement Co., Sharon, Pa. Private communication.

Table 250 contains the analysis of a number of European slag cements, as given by various authorities. It will be seen that, despite the apparently great variations in practice, the ultimate composition of the finished cement falls within quite narrow limits. The range in composition of a good slag cement may be considered to be about: SiO_2, 22 to 30 per cent; $Al_2O_3+Fe_2O_3$, 11 to 16 per cent; CaO, 49 to 52 per cent; MgO, less than 4 per cent; S, less than 1.5 per cent; ignition loss, 2.5 to 7.5 per cent.

TABLE 250.

ANALYSES OF EUROPEAN SLAG CEMENTS.

Components.	Brunswick, Germany	Choindez, Switzerland.	Bilbao, Spain.	Donjeux.			Saulnes, France.
SiO_2	25.56	19.5	30.56	23.85	24.85	24.55	22.45
Al_2O_3	11.20	17.5	13.31	13.95	12.10	14.05	13.95
FeO	.....	....	0.25	1.10	3.85	1.85	3.30
CaO	49.70	54.0	45.01	51.40	49.20	49.25	51.10
MgO	.....	....	2.96	1.95	1.75	1.60	1.35
S	.....	....	*4.63	.....	1.30		
SO_3	.....	....	†1.41	0.45	1.35	0.60	0.35
Loss on ignition	.....	....	.....	7.05	5.65	7.75	7.50

* CaS. † $CaSO_4$.

Physical Properties.

Specific gravity.—The specific gravity of slag cements usually ranges from 2.7 to 2.9, as compared with the 3.15 which may be considered a fair average for the specific gravity of a good Portland cement. The slag cements are, therefore, appreciably lighter than Portlands, and more bulk is obtained for the same weight. The following determinations of the specific gravity of three American slag cements have been made at Philadelphia:

Toltec	2.861
Climax	2.888
Penn	2.831

Aside from its use as a method of distinguishing slag cements from Portlands, the determination of the specific gravity of the cement is of little engineering importance. A point which is of engineering importance, however, appears to have been overlooked by experimenters. So far as the writer knows, the relative specific gravities of set briquettes, composed of neat-slag cement and neat-Portland cement respectively, have never been determined. A knowledge of the two values would be of service, at times, in selecting the type of cement to be used. For some purposes, as in dams, a heavy material is preferable; for others, as in floors, the lighter cement would be better.

Color of slag cements.—Slag cements can usually be distinguished from Portlands by being much lighter in color and slightly different in tint, while from most natural cements they differ markedly in tint. They are commonly bluish-white to lilac, the exact color of any specimen depending partly on the respective colors of the lime and the slag which have been used in its manufacture, but more largely on

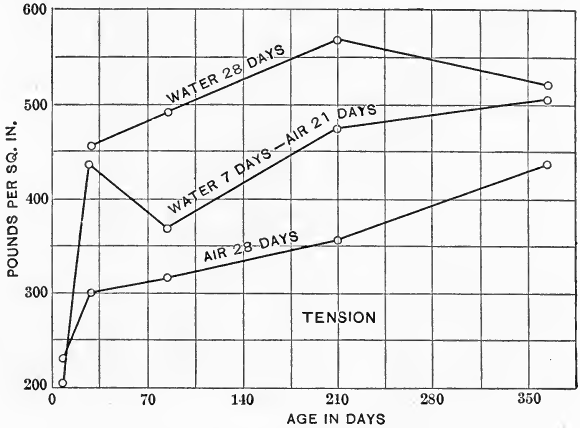

FIG. 164.*—Effect on tensile strength of slag cements of hardening in air or in water. (Tetmajer.)

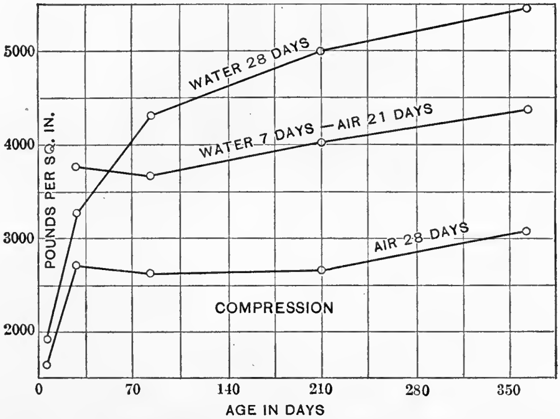

FIG. 165.*—Effect on compressive strength of slag cement of hardening in air or in water. (Tetmajer.)

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* From Johnson's "Materials of Construction", p. 576.

the relative proportions in which these ingredients have been mixed. Slag cements do not stain masonry; and an imported cement of closely related origin (Meier's Pozzuolan) has long been in favor in this country for architectural uses, because of this non-staining property.

Rapidity of set.—Normally slag cements are slower setting than Portlands. Whether this property is a disadvantage or not will depend on the use to which the cement is to be applied. As before mentioned the rapidity of set increases naturally with the amount of alumina in the slag. Set can be artificially hastened by the addition of puzzolanic material to the cement; burned clay, active forms of silica, slags high in alumina, etc., are additions which are both effective and cheap. The treatment of the cement during manufacture with alkalies to accelerate the set has already been discussed.

Strength.—While slag cements fall below high-grade Portlands in tensile strength, good American slag cements develop sufficient strength to pass the usual specifications for Portlands. Tested neat they do not approximate so closely to the Portlands as they do if tested in 2:1 or 3:1 mortars. Part of this property may be due to the fact that they are in general ground finer than Portlands, especially than foreign Portlands. Prof. W. K. Hatt recently made a large series of tests on American slag cements, and reported that there was no noticeable deficiency in strength of briquettes kept in air as compared with those kept in water. Other investigators have arrived at opposite conclusions; and it is probable that these conflicting results arise from differences in the chemical composition of the various brands tested.

Resistance to mechanical wear.—Slag cements are notably deficient in this property, and are therefore not available for use for the surface of pavement, floors, etc., where this quality must be highly developed; they seem to be well fitted, however, for pavement foundations, or indeed for any work which will not be exposed to dry air, and in which a high strength is not necessary.

Ratio of tensile to compressive strength.—This ratio, which is of importance (as noted in the discussion of Portland cements) seems to be much lower for slag cements than for Portlands. In the case tabulated below, the results of tests show the ratio for slag cement to average 5.3:1, in place of the 10:1 ratio, which is a fair average for Portland cements.

The average value for $\frac{\text{compressive strength}}{\text{tensile strength}}$ for the whole series is 5.3.

TABLE 251.

TENSILE *vs.* COMPRESSIVE STRENGTH OF SLAG CEMENTS.

Mixture.	Test.	7 Days.	28 Days.	7 Days.	28 Days.	7 Days.	1 Month.
Neat cement.	Tension	441	528	480	503		
" "	Compression	2054.5	. . .	2470	2830		
	$C \div T$	4.66	. . .	5.15	5.63		
1 cement, 3 sand. .	Tension	170	219	145	200	171	243
" " . .	Compression	486.5	. . .	933	938	1138	1529
	$C \div T$	2.86	. . .	6.44	4.69	6.65	6.29

List of references on properties and testing of slag cements.— In addition to the list given below, many of the papers cited on pages 664–665 will be found to contain data on the properties and testing of slag cements.

Bonnami, H. Fabrication et controle des chaux hydrauliques et des ciments. 8vo, 276 pp. Paris, 1888.

Candlot, C. Ciments et chaux hydrauliques. 8vo. Paris, 1889.

Detienne, H. Manufacture and properties of slag cement. Revue universelle des mines, Sept., 1897.

Elbers, A. D. Notes on the manufacture and properties of blast-furnace slag cement. Eng. and Mining Journal, vol. 64, pp. 515–516. 1897.

Hatt, W. K. American slag cements. 21st Ann. Rep. Proceedings Indiana Engineering Soc., pp. 45–65. 1901. Also in Engineering News, March 7, 1901.

Le Chatelier, H. Tests of hydraulic materials. Trans. Am. Inst. Min. Eng., vol. 22, pp. 3–52. 1894.

Mahon, R. W. Slag-cement experiments. Journal Franklin Institute, vol. 137, pp. 184–190. 1894.

May, E. Slag cement: its production and properties. Stahl und Eisen, March and April, 1898. Abstract in Iron Age, Sept. 1, 1898.

Prost, M. A. Note sur la fabrication et les propriétés des ciments de laitier. Annales des Mines, 8th series, vol. 16, pp. 158–208. 1889.

Redgrave, G. R. Manufacture and properties of slag cement. Proc. Institution Civil Engineers, vol. 105, pp. 215–230. 1891.

Rohland, P. Influence of catalysers on velocity of hydration of cements. plasters, and limes. Zeitschrift anorg. Chemiè, vol. 31, pp. 437–444. Abstract in Journal Soc. Chem. Industry, vol. 21, p. 1233. 1901.

U. S. Army Board of Engineers. Report on Steel Portland Cement. 8vo, 112 pp. Washington, 1900.

Whiting, J. The definition of Portland cement. Engineering Record, July 30, 1898.

Anon. The distinction between slag and Portland cements. Engineering Record, July 9, 1898.

Specifications for slag cement.—So far as known, the only American specifications for slag cement are those prepared and published in 1902 by the Engineer Corps, U. S. Army. These are reprinted below.

SPECIFICATIONS FOR PUZZOLAN CEMENT.

Engineer Corps, U. S. A., 1902.

(1) The cement shall be a Puzzolan of uniform quality, finely and freshly ground, dry, and free from lumps, made by grinding together without subsequent calcination granulated blast-furnace slag with slaked lime.

(2) The cement shall be put up in strong sound barrels well lined with paper, so as to be reasonably protected against moisture, or in stout cloth or canvas sacks. Each package shall be plainly labeled with the name of the brand and of the manufacturer. Any package broken or containing damaged cement may be rejected, or accepted as a fractional package, at the option of the United States agent in local charge.

(3) Bidders will state the brand of cement which they propose to furnish. The right is reserved to reject a tender for any brand which has not given satisfaction in use under climatic or other conditions of exposure of at least equal severity to those of the work proposed, and for any brand from cement works that do not make and test the slag used in the cement.

(4) Tenders will be received only from manufacturers or their authorized agents.

(The following paragraph will be substituted for paragraphs 3 and 4 above when cement is to be furnished and placed by the contractor:

No cement will be allowed to be used except established brands of high-grade Puzzolan cement which have been in successful use under similar climatic conditions to those of the proposed work and which come from cement works that make the slag used in the cement.)

(5) The average weight per barrel shall not be less than 330 lbs. net. Four sacks shall contain 1 barrel of cement. If the weight as determined by test weighings is found to be below 330 lbs. per barrel, the cement may be rejected, or, at the option of the engineer officer in charge, the contractor may be required to supply, free of cost to the United States, an additional amount of cement equal to the shortage.

(6) Tests may be made of the fineness, specific gravity, soundness, time of setting, and tensile strength of the cement.

(7) **Fineness.**—Ninety-seven per cent of the cement must pass through a sieve made of No. 40 wire, Stubb's gauge, having 10,000 openings per square inch.

(8) **Specific gravity.**—The specific gravity of the cement, as determined from a sample which has been carefully dried, shall be between 2.7 and 2.8.

(9) **Soundness.**—To test the soundness of cement, pats of neat cement mixed for five minutes with 18 per cent of water by weight shall be made on glass, each pat about 3 inches in diameter and $\frac{1}{2}$ inch thick at the center, tapering thence to a thin edge. The pats are to be kept under wet cloths until finally set, when they are to be placed in fresh water. They should not show distortion or cracks at the end of twenty-eight days.

(10) **Time of setting.**—The cement shall not acquire its initial set in less than forty-five minutes and shall acquire its final set in ten hours. The pats made to test the soundness may be used in determining the time of setting. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire $\frac{1}{12}$ inch in diameter loaded to $\frac{1}{4}$ lb. weight. The final set has been acquired when the pat will bear, without being appreciably indented, a wire $\frac{1}{24}$ inch in diameter loaded to 1 lb. weight.

(11) **Tensile strength.**—Briquettes made of neat cement, after being kept in air under a wet cloth for twenty-four hours and the balance of the time in water, shall develop tensile strengths per square inch as follows:

After seven days, 350 lbs.; after twenty-eight days, 500 lbs.

Briquettes made of one part cement and three parts standard sand by weight shall develop tensile strength per square inch as follows:

After seven days, 140 lbs.; after twenty-eight days, 220 lbs.

(12) The highest result from each set of briquettes made at any one time is to be considered the governing test. Any cement not showing an increase of strength in the twenty-eight-day tests over the seven-day tests will be rejected.

(13) When making briquettes neat cement will be mixed with 18 per cent of water by weight, and sand and cement with 10 per cent of water by weight. After being thoroughly mixed and worked for five minutes the cement or mortar will be placed in the briquette mould in four equal layers and each layer rammed and compressed by thirty blows of a soft brass or copper rammer, $\frac{3}{4}$ of an inch in diameter or $\frac{7}{10}$ of an inch square, with rounded corners, weighing 1 lb. It is to be allowed to drop on the mixture from a height of about half an inch.

When the ramming has been completed the surplus cement shall be struck off and the final layer smoothed with a trowel held almost horizontal and drawn back with sufficient pressure to make its edge follow the surface of the mould.

(14) The above are to be considered the minimum requirements. Unless a cement has been recently used on a work under this office, bidders will deliver a sample barrel for test before the opening of bids. If this sample shows higher tests than those given above, the average of tests made on subsequent shipments must come up to those found with the sample.

(15) A cement may be rejected in case it fails to meet any of the above requirements. An agent of the contractor may be present at the making of the tests, or, in case of the failure of any of them, they may be repeated in his presence. If the contractor so desires the engineer officer in charge may, if he deems it to the interest of the United States, have any or all of the tests made or repeated at some recognized testing laboratory in the manner herein specified, all expenses of such tests to be paid by the contractor. All such tests shall be made on samples furnished by the engineer officer from cement actually delivered to him.

CHAPTER XLV.

SLAG BRICKS AND SLAG BLOCKS.*

UNDER the names of "slag brick", "slag tile", "slag block", "scoria brick", etc., two very different products have been included by various writers. Both products are made from blast-furnace slag, but the two classes differ so greatly in their methods of manufacture and properties that it seems necessary to describe them separately. This has accordingly been done, the names "slag bricks" and "slag blocks" being supplied to the respective classes. As here used, the term "slag brick" will be confined to those bricks, tiles, etc., which are made by mixing slaked lime with ground slag, molding the mixture by hand or in a brick-machine, and drying or steaming the product. The term "slag blocks", on the other hand, will be applied to the products made by pouring molten slag into brick-shaped molds.

Slag Bricks.

The structural products included in this chapter under the head of "slag bricks" include those which are made by mixing granulated slag with slaked lime or with slag cement, molding the mixture in a brick-press or by hand, and drying it in the air, with or without the use of steam. It will be noted that all the raw materials used in this industry are the same as those utilized in the manufacture of slag cement; and indeed the manufacture of slag bricks may be considered as being merely a specialized phase of the slag-cement industry.

Though the slag-cement industry of the United States is in a fairly satisfactory condition no serious attempt seems to have been made to prepare slag bricks, tile, pipes, etc., on a commercial scale. Small amounts of slag bricks have been made for use about the mills and furnaces

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* Over half of the material contained in this chapter is reprinted, by courtesy of Engineering News, from an article by the present writer published in its issue of April 30, 1903.

and for the local market, but apparently no attempt has been made to extend the manufacture.

Methods of manufacture.—The slags used are basic blast-furnace slags, but a somewhat greater range in composition is allowable for slag bricks than when the slags are to be used in cement-manufacture. The analyses quoted in the present chapter may be regarded as fairly representative of the class of slags used in slag-brick manufacture. It will be seen that the silica ranges from 22.5 per cent to 35 per cent; the alumina and iron oxide together, from 16.1 per cent to 21 per cent; the lime, from 40 per cent to 51.5 per cent. As in slag cements, sulphur is an objectionable constituent. Much of it, fortunately, is removed during the process of granulating the slag.

The general steps in slag-brick manufacture may be stated as follows; Slags of proper composition are granulated by being run into a stream of cold water immediately upon issuing from the furnace. This causes the slag to break up into little porous particles, thereby greatly reducing the expense of subsequent grinding: Granulation also confers hydraulic properties on the slag, and removes part or all of its contained sulphur. The granulated slag is dried and pulverized. Powdered slaked lime is added in sufficient uantity to bring the total calcium oxide content of the mixture up to about 55 per cent. This mixing, as well as the previous burning and slaking of the lime, must be carefully and thoroughly done in order to prevent subsequent disintegration of the bricks. Usually, during or after the mixing, a small amount of water is added. The mixture is then molded into shape, either by hand or in a brick-machine. After shaping, the bricks are dried in the open air, this usually taking six to ten days in dry weather. In the best practice, the bricks are retained for several months, after drying, in order that they may be well hardened before marketing.

Though over 90 per cent of the total production of slag brick is at plants following the above methods, three other methods may be briefly noted. At a few plants the granulated slag is mixed, without drying, with the unslaked lime; the slag furnishing sufficient water to slake the lime. Slaking in this way is very imperfectly done, however, and the practice should never be followed if high-grade bricks are expected. At a few other plants, notably at the Bilbao plant described below, slag is mixed with slag cement instead of with lime. At certain English plants, also noted below, the slag bricks are hardened in steam cylinders like the cylinders used in lime-sand brick manufacture.

Slag bricks vary in color from a grayish white to dark gray. They weigh less than clay bricks of equal size, are said to require less mortar in laying up, and are at least equal to clay bricks in crushing strength. The product usually seems to find a ready market, though, of course, the low value of the material, relative to its bulk and weight, precludes long railroad transportation.

Methods at special plants.—Slag bricks were manufactured at the Cleveland Slag Works, Middlesborough, England; but the manufacture has been discontinued for some years At this plant the wet granulated slag was mixed with "selenitic lime" (see Ch. XV) instead of with common lime. The selenitic lime was composed of 80 per cent quicklime, 10 per cent gypsum, and 10 per cent iron oxide. About 670 lbs. of this selenitic lime was sufficient for 1000 bricks. The mixture of slag and lime was pressed to shape in a brick-press; and the bricks were stacked in sheds for a week, to harden enough to handle well. After this they were stacked in the open air for five or six weeks more, when they were ready for use. The bricks were dull-gray in color, and very hard and tough. Buildings onstructed of them over twenty years ago are still in a good state of preservation. The manufacture of slag bricks at these works was given up for reasons not connected with the technical value of the product, which seems to have acquired an excellent local reputation

At Vitry, France, the manufacture * of slag bricks and pipes is carried on in connection with the manufacture of slag cement. The bricks are made by mixing 60 parts of slaked lime with from 250 to 300 parts of granulated slag. Sufficient water is added to this mixture to make a firm paste, from which the bricks are molded in hand- or steam-presses. These slags are found to be especially useful for foundations or basement work, pavements, etc. "Facing brick" are made from a similar mixture, with the addition of some fine sand. Sewer pipes are made from a mixture consisting of 500 kgs. of slag cement and 1 cu. m. of sand. This mixture is made into a stiff mortar, and forced into steel molds by iron rammers. The molds are removed as soon as the ramming has finished. The pipes are then dried for three days, after which they are immersed in water for twenty-four hours. They are then stacked in the factory ground for several months, after which they are ready for market.

Slag bricks are manufactured † on a large scale at Kralovedvoor, near Prague, Bohemia. The slags normally used at this plant vary in composition within the following limits;

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* Engineering News, Jan. 1, 1897.

† Engineering and Mining Journal, April 16, 1898.

	Per Cent.
Silica (SiO_2)	25.8 to 27.0
Alumina (Al_2O_3)	17.3 " 19.3
Iron oxide (FeO)	1.5 " 1.7
Manganese oxide (MnO)	0.0 " 0.1
Lime (CaO)	51.4 " 51.5
Magnesia (MgO)	0.4 " 2.5
Sulphur (S)	1.3 " 1.8

As the slag issues from the furnaces it is run into an inclined iron trough in which cold water is flowing. In addition to granulating the slag, a considerable portion of the sulphur is removed in this way. The granulated slag is run into tanks, from which it is carried to the mixing floor, as required, by conveyors. Here the slag is dumped into mixers, together with thoroughly slaked lime in a pasty condition. The lime is obtained by the calcination of a limestone of the following range in composition:

	Per Cent.
Silica (SiO_2)	0.2 to 0.6
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	0.2 " 0.8
Lime carbonate ($CaCO_3$)	97.0 " 98.4
Magnesium carbonate ($MgCO_3$)	0.9 " 1.9

The mixture is then molded into shape under pressure in a brick-machine with a capacity of 1000 bricks per hour. These bricks are taken to the drying house, where they remain about eight days, at the end of which time they are sufficiently hard to stand transportation. In the size usually made, the dry bricks weigh about 4.75 kgs. each, and will stand a pressure of 18 kgs. per square centimeter. In color they vary from nearly white to grayish. Cement and mortar adhere to them as well as to clay bricks.

Occasionally bricks are made at this plant from slags of the following average composition, derived from the smelting of a manganiferous ore different from that commonly used at these furnaces:

	Per Cent
Silica (SiO_2)	33.00
Alumina (Al_2O_3)	18.67
Iron oxide (FeO)	1.00
Manganese oxide (MnO)	4.25
Lime (CaO)	40.00
Magnesia (MgO)	2.33
Sulphur (S)	1.33

Bricks made from this slag are dark colored, owing to the comparatively large percentage of manganese present. More lime must be used, in proportion to the slag, and the bricks made from this slag require a longer time to dry and harden than is needed by those made from the ordinary slag.

Slag bricks are made at Ekaterinoslav,* Russia, from blast-furnace slags showing the following range in composition:

	Per Cent.
Silica (SiO_2)	22.5 to 35.0
Alumina (Al_2O_3)	14.0 " 15.0
Iron oxide (Fe_2O_3)	1.1 " 3.3
Manganese oxide (MnO)	0.0 " 0.3
Lime (CaO)	45.0 " 51.0
Magnesia (MgO)	tr. " 1.4
Sulphur (S)	0.3 " 0.4
Loss on heating	2.3 " 7.5

The slag is granulated, sieved on a revolving screen, dried, and ground in a ball mill. Lime is slaked and sieved. Enough of this slaked-lime powder is added to the slag to bring the lime (CaO) content of the mixture up to about 55 per cent. With slags of the range in composition above indicated, this would require the mixture to consist of from 5 to 12 parts of lime to 100 parts of slag. The mixing is carried on in a screw mixer, and the powdered mix is then pressed into brick in a dry press. On issuing from this press the bricks are set aside to harden, and at the end of six days are usually hard enough for use. Their tensile strength is about 312 lbs. per square inch; and the crushing strength varies from 1250 to 5600 lbs. per square inch; both, of course, increasing with age. The bricks are gray in color, well shaped, weigh less than stone, and require little mortar in laying up. They withstand temperature changes well, and are particularly well adapted for use in damp situations or under water.

Toldt has described the manufacture of slag bricks at Bilbao, Spain, where the blast-furnace slag from the Vizcaya furnaces is used. Slag cement is made by mixing three parts of granulated and dried slag with one part powdered slaked lime, and grinding this mixture in a ball mill. The bricks are then made by mixing one part by volume of this cement with four parts of wet granulated slag, and pressing this mixture into shape in a brick-press. A Belgian form of press with twelve molds is used. This turns out twenty bricks per minute, with thirteen workmen.

It will be noted that in a slag brick made in this fashion the strength of the brick must be almost entirely derived from the slag cement used in the mixture, for the uncrushed slag will be almost inert.

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* Engineering and Mining Journal, 1896.

Hardening in steam-cylinders.—A new method of slag-brick manufacture has recently been introduced * in England. In this process the use of lime is dispensed with (except when slags carrying less than 35 per cent CaO are used), while a hardening cylinder is employed exactly as in the manufacture of lime-sand brick (see pp. 136–140). The slag is allowed to cool normally; it is then broken up and fed to an edge-runner mill, where it is crushed and ground, and falling thence into a deep pit under the mill, it is collected by an elevator and thrown on a 10-mesh screen. All capable of passing this goes to the mixer, the coarser particles being rejected and returned to the mill for further grinding. "The ground slag is moistened in the mixer with from 5 to 10 per cent of water, and is then delivered by the mixer into the brick-making machine, where it is molded into bricks under great pressure, the pressure employed being from 100 to 150 tons on each brick. As the bricks are made they are stacked onto steel platform-wagons made to carry from 700 to 800 bricks. The loaded wagons are allowed to stand for twelve hours, to allow the bricks to take a slight initial set, after which they are run into the steel chamber, and the bricks are here subjected to the action of steam at a pressure of from 105 to 120 lbs. per square inch. Ten hours under this treatment is sufficient to harden the bricks and render them on withdrawal ready for building purposes.

"It is necessary that the machinery employed should be of a very strong and durable character. For effecting the grinding an edge-runner mill is most suitable, as it is not easily put out of order by the iron which is often found in the slag in large pieces. The roller rims and false bottom should be of steel, preferably manganese steel; and the perforated grate should also be of steel. the rollers should be made of a suitable weight, depending upon the hardness of the slag—generally from three to five tons each. Their width should not exceed 12 inches.

"A specially designed brick-making machine is employed. This consists of a rotating table containing the molds, a feeding-pan, and powerful toggle-press. As the table revolves, the molds pass alternately under the feeding-pan where they are fed with the charge of material, then under the press, and a further rotation brings the mold over the ejecting plunger and the brick is discharged ready for removal. The machine is capable of exerting a pressure on each brick of 150 tons, and is fitted with a simple contrivance to insure the corners of the bricks being well pressed up. Its operation is first to give the material in the mold at

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* Sutcliffe, E. R. Utilization of blast-surface slag. Amer. Mfr. and Iron World, vol. 74, pp. 555–563, May 5, 1904.

a top pressure by means of a wedge-shaped plunger, forcing the material well into the sides and corners of the mold, and a final pressure from below, which completely presses out the indentation made by the wedge-shaped plunger and gives a good finish to the sides and corners of the brick. The necessity of this arrangement will be apparent when it is understood that ground slag does not become plastic under pressure as does ordinary clay, and that a material when filled into a mold by gravity naturally piles in the center, and if directly pressed would produce bricks of greater density in the center than at the sides.

"The hardening-chamber s like a boiler without flues, 45 ft. long by 6 ft. in diameter. In contains 6000 bricks, and must be capable of withstanding the pressure of steam, which is used for their indurating. One end of the chamber is removable and held in place by hinged bolts threaded on to a back ring, the joint being made by a projection on the cover fitting into a recess in the shell, the bottom of the recess being filled with ordinary red rope packing. The chamber will permit of two steamings per day—one during the daytime and the other at night. Hence each chamber with high-pressure steam serves for 12,000 bricks per day.

"The brick wagons must be strongly constructed, as any deflection of the platform might tend to crack and spoil the bricks, which in the green state require some care in handling. It is necessary that roller or ball bearings be used for the axles, as under the action of the steam any oil or grease would be burnt out of ordinary bearings.

"It will be noted that no binding material whatever is mixed with the slag. The process is really the production of a concrete. In grinding the slag fine enough to pass a 10 per inch mesh a very large proportion of it is reduced to a fine dust, which acts as a hydraulic cement, the coarser particles forming the aggregate. Where the slag is very hard, and consequently only a small proportion of dust is produced, it is necessary to reduce a portion in a ball mill or other suitable fine-grinding machine. The precise action which takes place during the hardening is difficult to determine; but evidently the result is due to a combination being effected between the free lime found in all limy slags and the silica and alumina.

"It may be assumed that the silicious compounds in the slag become soluble in the presence of heat and moisture, in which condition it is readily attacked by the free lime present in the slag.

"With some slags high-pressure steam gives better results than low-pressure, besides requiring less time to effect the hardening. In speaking of high-pressure steaming, it is to be understood that this refers to any pressure above the atmosphere and low pressure to at or under this. With other slags low pressure is quite as effectual as, and in some instances is better than, high pressure. To determine which is the most suitable process is a question for experiment with the particular slag. Where low-pressure steaming is adopted the chambers may either be made of thin sheet steel or tunnels may be constructed of brickwork. In the author's experiments a steel high-pressure chamber was used steaming up to 150 lbs. pressure per square inch and for low pressure a chamber constructed of brickwork. In general, for low-pressure steaming for about forty hours, and for high-pressure steaming twenty hours, will be found most suitable and convenient. The author has not formed a definite opinion as to what element in the slag causes the different effect in the action of high- and of low-pressure steam, but is inclined to think that it is principally due to the proportion of sulphur in the slag. During the steaming some sulphur is driven out of the bricks, and the final hardening does not seem to be completed until this volatile or unfixed sulphur is driven out or combined. It is probable that the sulphide of calcium present is slowly being split up, the hydrogen of the water combining with the sulphur forming sulphuretted hydrogen, and the oxygen with the calcium forming lime. By subjecting the slag to steam, thus keeping it moist and hot at the same time, this action is accelerated.

"Generally slags high in sulphur can be hardened best under prolonged low-pressure steam, and in one or two instances no hardening effect was produced by high-pressure steam, whereas low-pressure steam produced the desired effect. From this it would seem that the chemical action is only accelerated up to a certain temperature, and that at a higher temperature a different effect is produced; or it may be that at a higher temperature the action is too violent, causing an expansion and separation of the particles without actually producing cracks or disintegration of the bricks, but sufficient to prevent the final combination. Seemingly the presence of this unfixed sulphur retards the action of the lime on the silicates and aluminates, and only when it is finally driven off can the full combination be effected.

"In the case of a slag which falls to powder on exposure to the atmosphere a grinding-mill is unnecessary; and with some slags of this character it is only necessary to moisten and then press it into bricks and harden as before. Again, with others it would be necessary to grind a portion to dust in a ball mill before the setting could be obtained. In the former case the slag powder would consist of a fine dust mixed with coarser particles, and in the latter case it would be like a fine even-grained sand without any really fine dust.

"The slag used for brickmaking should preferably be new; but it has been found that a slag which had been exposed for twenty years still possessed setting properties when acted upon by steam. One of the bricks exhibited was made in the summer of 1901 from slag which had been exposed to the atmosphere for over twenty years.

"In the case of a slag which disintegrates on exposure to the atmosphere, it would not be wise to use it directly after it has cooled unless the ground-moistened slag is permitted to stand until the free lime is thoroughly hydrated. This could be effected in silos erected directly over the brickmaking machine; and twenty-four hours in this condition would be sufficient. In general the better plan would be to allow the slag to stand for about ten days before being used, as in such cases the grinding would be facilitated by the disintegrating.

"The slag for brickmaking should preferably be cast in thin layers capable of being easily broken up in sizes suitable for being passed into the grinding-mill, rendering a stone-breaker unnecessary.

"The bricks are almost perfect in form, there being no twisting or distortion produced by the induration, and in strength and other qualities they will compare with the best qualities of clay bricks.

TABLE 252.

CRUSHING STRENGTH OF INDURATED SLAG BRICKS.

No. of Specimens.	Dimensions in Inches.	Cracked at Tons per Sq. Ft	Crushed at Tons per Sq. Ft	Remarks.
1	$9 \times 4\frac{3}{8} \times 2\frac{7}{8}$	227	340	
1	$9 \times 4\frac{3}{8} \times 2\frac{7}{8}$	303	375	Not completely crushed
1	$9 \times 4\frac{3}{8} \times 2\frac{7}{8}$	227	375	Not completely crushed
1	$9 \times 4\frac{3}{8} \times 2\frac{7}{8}$	246	370	

"Objections have been raised against granulated slag bricks on account of their porosity, which ranges in some cases as high as 15 per cent. No objections of this kind can be raised against these indurated slag bricks, the absorption being remarkably low, as shown in Table 253.

"The bricks before testing were thoroughly dried at 212° and then immersed for twenty-four hours.

TABLE 253.

POROSITY OF SLAG BRICKS.

No.	Dimensions in Inches.	Weight Before Immersion.	Weight After Immersion.	Gain in Weight.	Per Cent.
1	$9 \times 4\frac{3}{8} \times 2\frac{7}{8}$	8 lbs. 10 oz.	9 lbs. 1 oz.	7 oz.	5.07
2	$9 \times 4\frac{3}{8} \times 2\frac{3}{4}$	8 lbs. 12 oz.	9 lbs. 4 oz.	8 oz.	5.71

"These bricks were tested by burning them in an ordinary continuous brick kiln, and a brick treated in this way withstood the fire successfully and is still a good hard brick, the only change being in the color, which is now a light buff. During the burning the loss in weight averaged 6 ounces, which equals 4.47 per cent; and the absorption after burning was 16 ounces, or 11.9 per cent, after twenty-four hours' immersion.

"The following is the estimated cost of production, based on a production of 10,000 bricks per day of ten hours:

Labor.	£	s.	d.
1 man at grinding-mill at 6d. per hour	0	5	0
2 men at brickmaking machine, taking off, at 6d. per hour	0	10	0
1 youth attending to moistening of material	0	3	6
4 wheelers and stackers at 6d. per hour	1	0	0
1 foreman	0	6	0
	2	4	6

Cost in labor per 1000 bricks, say 4s. 6d.

"To this must be added the cost of getting the slag to the machinery, wear and tear, depreciation, and such charges as may be added for power and steam.

"As regards the slag, this should be run from the furnaces on to a level floor and then broken up and taken to the machinery. This will mean a little extra cost over that of running the slag in wagons and depositing it in balls on the slag heap; but 6d. per ton should cover the whole cost of casting the slag in this way and running it to the machinery. Wear and tear on machinery will necessarily be high, considering the wearing action of the slag. This will be well provided for at 1s. 6d. per 1000 bricks.

"As to power and steam, this would be generated from the furnace gases, and if not used for this purpose might be considered as wasted; but assuming this at the value of coal, if such were used we should require 2½ tons of coal per day, which, at 10s. per ton, works out at 2s. 6d. per 1000 bricks. If we allow 6d. per 1000 for generation, we get 3s. per 1000 bricks.

"The cost of a complete plant such as described would be about £3000, including buildings and all requirements. Taking depreciation at 7½ per cent on the whole, and reckoning on 300 working days, we get 15s. per day, or 1s. 6d. per 1000 bricks.

SUMMARY OF COST OF PRODUCTION PER 1000 BRICKS.

	s.	d.
Cost of labor	4	6
Slag at 6d. per ton (4 tons)	2	0
Wear and tear	1	6
Power and steam	3	0
Depreciation	1	6
Oils, sundries, etc.	0	6
Total cost of production	13	0

"The above calculation is based on only producing 10,000 bricks per day. The plant would be capable of making up to 12,000 per day; so that by only calculating on this reduced output sufficient allowance is made for unforeseen losses. If a larger plant were installed the cost could be very considerably reduced; on a plant producing, say, 20,000 bricks per day, the cost per 1000 should not be more than 10s. to 11s.

"This refers more particularly to limy slags; but in the case of slags not so rich in lime, hydrated lime can be added to the ground slag and the hardening effected in the same way, but in such cases the cost of production is increased by the cost of this added lime.

"As before pointed out, most limy slags have setting properties without being steamed; and with slags containing from 40 to 48 per cent of lime, bricks may be made by merely grinding and pressing the material and permitting the bricks to stand out in the open air, the same conditions being observed as in making granulated slag bricks, but this method is not so satisfactory as the hardening by steam. In many slags there is a proportion of soluble salts which tend to spoil the bricks when allowed to harden naturally by appearing as efflorescence. This in some cases is so violent that the outer crust will be forced away from the brick; but the same effect does not happen when they are steamed, the steaming either turning the salts into a stable compound or driving them off.

"These bricks will withstand the weather equally with a high-class clay brick. Bricks have been exposed to the weather the whole winter and no effect whatever is noticeable upon them. They have been soaked, then frozen, and afterwards put into hot water without deterioration."

Slag Blocks.

Under this heading will be considered all these products ("slag blocks", "slag tiles", etc.) made by running molten slag, direct from the furnaces, into molds of proper shape. The term *slag block* will be employed as a general but distinctive name for this class of products in order to distinguish them from the *slag bricks* made by mixing granulated slag with slaked lime, which have been discussed in previous sections of this chapter.

Slag blocks, if properly made, are stronger than slag bricks. They are, however, impervious to air and moisture; and on that account are not good building materials, for dwellings constructed of them are apt to be damp and unhealthful. Their chief uses are for foundations or for paving blocks, for the latter of which they are particularly well adapted.

Many smelters and furnaces have made small amounts of slag blocks for local use. For the past thirty years or so a considerable quantity have been made in the Lehigh iron district of Pennsylvania, their earliest recorded use being in the slag-block pavements laid in Philadelphia about 1876.

The properties required in a slag block to be used for paving work are density, resistance to abrasion, toughness, and roughness of surface. These properties are found to vary with the chemical composition of the slag, the rapidity with which the slag is allowed to cool, and the character of the moulds used. By properly varying the last two factors, slags of almost any composition can be utilized in this industry.

The three requisite properties first mentioned—i.e., density, resistance to abrasion, and toughness—vary directly with the rate of cooling, the slowly cooled blocks being the best. Blocks cast in sand molds and heavily covered with loose sand, cool very slowly, and give very much better results than those cast in iron molds. Slowness in cooling, however, requires much greater storage space than if rapid cooling is practiced; and casting in sand molds demands a higher grade of workmanship than casting in iron molds.

The roughness of surface—or non-slipperiness—of blocks intended for paving use is highly important, especially as slipperiness has been the chief defect charged against slag blocks, which defect is prevalent in blocks cast in iron moulds. In English practice it has been overcome by casting the block in a double size mold, having a projection inside which results in a notch on the slag block. The block is, after coating, split apart at this notch, and the rough fracture-surface of each half is laid uppermost in paving. This method of avoiding slipperiness adds considerable to the labor cost of the blocks, and is therefore not well adapted to American practice. Slag blocks cast on a sand bed are free from the defect noted (slipperiness); or at least it can be avoided if sufficiently coarse sand be used.

Slag blocks manufactured by the Tees Scoria Brick Company, of

Middlesborough, England, have been somewhat extensively employed * as street pavement in Rotterdam. Holland clay bricks, limestone blocks, and porphyry bricks are employed in the same city, and will be useful for comparison with the slag blocks. The foundation, in all cases, is simply a bed of sand, carefully packed. The thickness or depth of pavement laid on this varies, according to the paving material, as follows: Clay bricks, 4⅓ inches; slag blocks, 5 inches; limestone or porphyry blocks, 6 inches. The cost of material and laying per square yard is: Clay bricks, 62½ cents; limestone blocks, 62½ cents to $1.25; slag blocks, $1.25; porphyry blocks, $1.56. No data as to proportions of each pavement in use, or durability of the different types, are available. The adjunct director of public works of Rotterdam stated that for light traffic the clay-brick pavements were regarded as the best; for medium traffic, slag blocks or limestone; for heavy traffic, porphyry blocks.

The manufacture of slag blocks from copper slags at Mansfeldt, Saxony, has been described † in detail by Egleston. The industry, as carried on in this locality, presents certain features of interest which warrant a somewhat lengthy abstract of the paper cited.

The slags used are high in silica, ranging from 40 per cent to 60 per cent. When cooled rapidly, they form a dark colored brittle glass, but if cooled with great slowness the product becomes gray and crystalline. These slowly cooled slags are both hard and tough, and therefore serviceable in the manufacture of structural material. The process employed at Krug Hutte is as follows:

The slag, as it comes from the furnaces, is carried in slag wagons to the molding ground, where the bricks are cast. The bed of the molds is sand, which has been sieved to remove coarse particles.

The bed is then carefully gone over with a shovel, which is pressed into it an inch or so to make the sand soft. It is then smoothed over with the shovel, and into the corners a piece of iron 0.18 m. to 0.20 m. long, and 0.15 m. wide is laid, inclined so as to facilitate the passage of the slag in the slag-runners which go round the whole space.

The molding-bed is then so divided by iron partitions pushed down into the sand as to give the size of blocks required. These partitions have several round holes, about 0.05 m. in diameter, near their tops, to permit the entrance of slag. Previous to use, the partitions are washed with clay and sprinkled with sand to prevent the slag from

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* Streets and Highways in Foreign Countries. Special Consular Report, vol. 3, p. 190, Washington, 1897.

† School of Mines Quarterly, vol. 12, pp. 112–117.

sticking to them. Around each of the molds thus formed is a space 0.20 m. wide, through which the slag flows. When all the partitions are in place, the bottom of each mold is made flat by pressing down into it a piece of sheet iron (of the same size as the compartment), attached to a handle.

When the molds are ready slag is brought from the furnace in slag wagons, and allowed to flow through the interspaces and into the molds. When the slag has about half filled a mold, a little sand is thrown on it to prevent too rapid cooling. When the molds are entirely full, they are covered with about a foot of sand and allowed to stand for forty-eight hours. At the end of this time the slag is cool, the sand is shoveled off, and the iron partitions removed.

During rainy weather the molding ground is kept covered with boards until the slag is ready for pouring, and as soon as this operation is finished the molds are again covered with boards.

The blocks are usually cubes, 0.15 m. on the edge, though larger sizes and different shapes are occasionally cast. The material which has solidified in the spaces between the molds is broken up for use as road metal.

At Koch Hutte similar processes are employed. Large blocks, however, are cast in cast-iron molds, with a cover that is shut down in order to compress the slag. Similar work is carried on at Kupferkammer Hutte.

Analyses of typical slags from the Mansfeldt district are given in Table 251.

A very interesting example of the manufacture of slag blocks or tiles from a copper blast-furnace slag has been described * by Braden as having been seen in operation at a furnace located near Santiago de Chile. His description is as follows:

The slag and matte are tapped from the blast-furnace into a slag-pot. After settling for a few moments the slag is poured from ladles into molds which are 6 inches square and 1 inch deep. The molds after being filled with slag are placed on a hearth which has a movable cover, and covers are placed on the molds as well as on the hearth. A very light heat is kept up, so that the slag cools very slowly. When it appears black the molds are lifted from the hearth and the slag tiles are dumped into cold water. The tiles thus made are very light and portable. When laid they have proven to be tough and durable. For this manufacture a slag carrying a considerable excess of iron

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* Trans. Am. Inst. Min. Engrs., vol. 26, pp. 52–53. 1896.

TABLE 254.

ANALYSES OF SLAG, MANSFELDT.

	Krug Hutte.	Koch Hutte.	Eckhardt Hutte.	Kupferkammer Hutte.	
Year	1888	1888	1888	1881	1881
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Lime	18.35	23.187	21.51	19.29	20.29
Magnesia	6.732	2.22	0.847	3.23	4.37
Alumina	14.825	17.001	16.525	16.35	15.67
Iron oxide	4.725	4.643	2.768	10.75	8.73
Manganese oxide	0.697	0.328	0.744		
Nickel and cobalt oxides	0.063	tr.	tr.		
Zinc oxide	1.165	0.692	0.934	1.26	1.11
Lead oxide	0.232	0.118	tr.		
Copper oxide	0.289	0.277	0.3	0.75	0.67
Silica	47.63	48.465	46.39	48.22	50.0
Fluor					
Total	97.708	96.931	90.018	99.85	100.84

	Kupferkammer Hutte.		Sangerhausen Hutte.	
Year	1881	1888	1881	1881
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Lime	19.50	19.15	33.10	23.40
Magnesia	8.02	3.677	1.67	0.87
Alumina	18.17	17.636	4.43	7.83
Iron oxide	5.89	7.213	4.37	7.47
Manganese oxide	.....	0.827		
Nickel and cobalt oxides	.....	0.038		
Zinc oxide	3.57	2.056		
Lead oxide	.....	0.065		
Copper oxide	0.23	0.333	0.25	.30
Silica	48.38	46.81	53.83	57.43
Fluor	0.99	......	2.09	1.97
Total	99.75	97.802	99.74	99.27

has been preferred. The tiles are sold for from $30 to $60 (pesos Chilenos) per thousand.

Slag blocks have been manufactured at a Montana copper smelter by a process which contrasts strongly with the practice at Mansfeldt and Santiago. The copper slag was poured into iron molds built up by putting together iron plates of proper form. The process was carried on in the open air and no covering of any kind was placed on the blocks. The slag in consequence cooled very rapidly. Though the product was, therefore, not as dense or tough as that secured at Mansfeldt, the Montana practice effected a great saving of time and space.

INDEX.

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