A fire-brick lining must be used. A thickness of 8 or 9 inches is more economical than a 4½-inch lining because it can be replaced without disturbing the concrete. Spaces must be left at the ends of the fire-brick lining to allow for expansion.

The concrete should be as rich as 1 : 2 :4 and the best aggregates are quartz sand and trap rock about ¾ inch maximum size. For high temperatures gravel and limestone aggregates should be avoided. Cinders of first-class quality should make durable walls when mixed with sand and cement in rich proportions.

Fences. Fences have been built of solid concrete, of mortar plastered on wire lath, of concrete rails set in concrete posts, and of concrete posts with galvanized fence wire between them. The last plan is the most common. For farm or division fences the length of posts may be 7 feet, allowing 3 feet of this to set into the ground, and the size may be 5 or 6 inches square at the bottom and 4 or 5 inches square at the top with ¼-inch rods in each corner. Forms are easily made singly or so as to mold several posts at once.

Silos. Silos of solid monolithic concrete built in circular forms may have walls 6 inches thick reinforced with ½-inch bars bent to circles and placed 12 inches apart. Occasional vertical bars are also necessary. The concrete must be mixed wet and placed very carefully so as to give a perfectly smooth interior surface, so solid and dense that the ensilage will not be dried out next to the wall.

Greenhouses. Greenhouses themselves, as well as the floors, tables, water troughs, hotbeds, and minor appurtenances, are being built of concrete. The directions throughout the various chapters in this treatise for structures of different classes will be found to apply to these details.

House Chimneys. Chimneys for residences may be of concrete if heavily reinforced, but the expense of forms usually will make them more costly than brick.

Chimney caps of concrete should be well reinforced to prevent cracking.

Residences. Residences are built of solid reinforced concrete; concrete blocks (see p. 629); concrete tile, plastered (see p. 629); and mortar plastered on metal lath (see p. 627).

Solid or monolithic concrete is especially adapted to fine residences and permits unique architectural treatment. Eventually with the development and consequent reduction in cost of form construction, reinforced concrete may be more generally employed for dwellings of small and moderate size.

CHAPTER XXX

CEMENT MANUFACTURE

This chapter contains a short historical sketch followed by a brief outline of the processes of modern cement manufacture, illustrated with views of typical machinery.

HISTORICAL

Lime must have been used by the Egyptians thousands of years before Christ, as the stones in the pyramids apparently were laid in mortar of common lime and sand. It is even thought by some that these ancients understood the principle of mixing lime and clay together to make a real cement.

Concrete was made by the Romans as early as several centuries before Christ. For most of their work, they used lime mixed with sand and stone, but understanding the value of puzzolana or volcanic ashes to render lime hydraulic, they employed these two materials in combination with the sand and stone for marine construction. For less important work, they often mixed lime and coarsely powdered brick with the aggregate. Vitruvius, writing in the first century, describes methods of making concrete with lime alone, and also gives as the formula for making it of slaked lime and Italian puzzolana:

12 parts of puzzolana, well pulverized.
6 parts of quartz sand, well washed.
9 parts of rich lime, recently slaked; to which is added
6 parts or fragments of broken stone, porous and angular, when intended for a "pise" or a filling in.

In the Middle Ages concrete was employed, after the Roman fashion, for both walls and foundations. In the former it was generally laid as a core faced with stone masonry. Large stones were often imbedded in the mass.

The fact that clay contained in certain limes rendered them hydraulic was discovered by John Smeaton, when studying the designs for the third Eddystone Lighthouse, about 1750. Early in the following century, Vicat, by his extended scientific researches in France, earned for himself the name of the founder of hydraulic chemistry.

In England, in 1796, James Parker made from nodules of argillaceous limestone, calcined and ground, what he called Roman cement. This process he patented, and from it the Natural cement industry was developed. It was Joseph Aspdin, of Leeds, England, who really invented Portland cement by discovering in 1824 that an artificial mixture of slaked lime and clay, highly calcined, formed a hydraulic product. On account of its resemblance in color and hardness to the Portland stone which was much used in England at that time, he called his invention Portland cement. Two patents had been granted in England a few years before his time, but as in these the materials were not heated to vitrification, hydraulic lime instead of cement was produced.

The Portland cement industry was not developed to any great extent until about twenty years after Aspdin's discovery, when J. B. White & Sons in Kent, England, commenced its manufacture. Later, Mr. John Grant gave a great impetus to Portland cement manufacture by experimental studies upon the practical action of cements, mortars and concretes under varied conditions. The results of his tests he presented to the Institution of Civil Engineers in 1866, 1871, and 1880.

The first manufactory for producing Portland cement in France was established toward the middle of the last century at Boulogne-sur-Mer. In Germany the first factory was erected soon after this, for the production of the Stettin Portland cement, and with such successful results that in 1900 Germany produced more Portland cement than any other country.

The discovery in the United States of a rock suitable for Natural cement was made in 1818 by Canvass White, an engineer connected with the construction of the Erie Canal, and Natural cement was made in Madison and Onondaga Co., N. Y., in that year. The first Natural cement in the Rosendale district was made at Rosendale, Ulster Co., N. Y., about 1823. Mr. D. O. Saylor was the founder of the Portland cement industry in the United States. His discoveries were made in the Lehigh Valley. He experimented from 1871 to 1875 and marketed cement in 1875.

PRODUCTION OF CEMENT

The total production* of hydraulic cement in the United States for 1908 was 52 910 925 barrels, of which 51 072 612 barrels were Portland cement, 1 686 862 barrels were Natural cement, and 151 451 barrels were Puzzolan or Slag cement. The average values per barrel were, for Portland cement $0.85, for Natural, $0.49 and for Puzzolan, $0.63.

The superior quality of Portland over Natural cement and the increasing

* Edwin C. Eckel in The Cement Industry in the United States in 1908.

economy of its manufacture is evinced by a comparison of these figures with those of 1890, when only 335 500 barrels of Portland cement were produced against 7 082 204 barrels of Natural cement. The imports of cement in 1890 were 1 940 186 barrels, and in 1908, 842 121 barrels.

The production of Portland cement in the United States by individual States is represented in the following table.

Production of Portland Cement in the United States in 1900 and 1908 by States

State	1900			1908		
	Producing Plants	Quantity barrels	Value	Producing Plants	Quantity barrels	Value
Pennsylvania	14	4 984 417	4 984 417	17	18 254 806	13 899 807
Indiana	1	30 000	37 500	7	6 478 165	5 386 563
Kansas	1	80 000	100 000	7	3 854 603	2 874 457
Illinois	3	240 442	300 552	5	3 211 168	2 707 044
New Jersey	2	1 169 212	1 169 212	3	3 208 446	2 416 009
Michigan	6	664 750	830 940	15	2 892 576	2 556 215
Missouri				4	2 929 504	2 571 236
California	1	44 565	89 130	4	2 480 100	3 268 196
Washington				2		
New York	8	465 832	582 290	7	1 988 874	1 813 623
Ohio	6	534 215	667 769	8	1 521 764	1 305 210
Iowa				1	1 205 251	1 176 499
Kentucky				1		
Tennessee				1		
Texas	2	26 000	52 000	2	917 977	924 039
Oklahoma				2		
South Dakota	1	38 000	76 000	1	809 306	1 057 433
Colorado	1	35 708	71 416	2		
Arizona				1	507 603	805 235
Utah	1	70 000	175 000	2		
Maryland				1	502 225	511 118
Virginia	1	58 479	73 099	1		
Massachusetts				1		
Alabama*				2	310 244	274 995
Georgia*				1		
Arkansas†	1	40 000	70 000			
North Dakota	1	400	1 200			
	50	8 482 020	9 280 525	98	51 072 612	43 547 679

* Product in 1900 combined with Virginia. †Product in 1900 combined with Missouri.

About 40% of the total production in 1908 was in the Lehigh Valley of Pennsylvania and New Jersey. In 1900, 73% came from that district.

PORTLAND CEMENT MANUFACTURE

Portland cement is made from a mixture of calcium carbonate and silicate of alumina.

The processes of manufacture differ with the natural state in which these materials are found, but the operation consists essentially of (1) pulverizing and mixing the two ingredients, (2) heating to a temperature which is near the melting point, i.e., calcining, (3) grinding to a fine powder.

If either of the raw materials occurs in a moist state it is generally customary to mix them wet, and after a preliminary grinding introduce them into the kilns. Dry raw materials for calcining or burning in the old style stationary kilns must be formed into plastic bricks with the aid of water, but the rotary kiln, invented in 1885 by Mr. Frederick Ransome, has revolutionized the manufacture of Portland cement by making it possible to introduce the mixed substances into the furnace, in either a dry or wet state, without hand labor.

After calcination, the methods of grinding the clinker are independent of the character of the raw materials or the type of kiln.

The Association of German Cement Manufacturers, to protect the good name of German Portland cement, requires that its members shall sign the following:*

The members of this Association are permitted to bring into the market under the term of "Portland Cement" only such material as is prepared from an intimate mixture of lime and clay materials as essential ingredients, burning to sintering and subsequent grinding to the finest of flour. They obligate themselves not to recognize as Portland cement any material which is prepared otherwise than above stated, or which during or after the burning has been mixed with foreign bodies, and to look upon the sale of other material under the name of Portland cement as deceiving the purchaser. These requirements are not to forbid the addition of not more than three per cent of other material to the Portland cement for the purpose of regulating the setting time.

The members of the Association further obligate themselves to furnish Portland cement which will in all respects meet the requirements of the Prussian Minister of Public Works.

When a consumer requires cement for a particular purpose, coarser grounp than the requirements, or colored, its preparation is allowable.

If a member of the Association offends the above given obligation, he shall be expelled from the Association. His expulsion is made known publicly.

The manufactured product of each member of the Association is tested yearly in the laboratory of the Association at Karlshorst near Berlin; and the results are given out at the General Meeting of the Association.

Raw Materials for Portland Cement Manufacture. The raw materials, as stated above, consist essentially of calcium carbonate and silicate of alumina. Their exact proportions are determined by their chemical composition. A usual ratio is about 75% carbonate to 25% silicate. The two substances occur in nature in so many forms that we have a

* Quoted in *Cement Age*, January 1909, p. 24.

large range of choice in raw materials. The following combinations are actually used in different cement manufacturing plants in the United States:

Cement rock and limestone
Limestone and clay.
Limestone and shale.
Marl and clay.
Chalk and clay.
Limestone and slag.
Alkali waste and clay.

Cement rock is an argillaceous limestone, rather soft in texture, which in the Lehigh Valley usually requires from 10% to 20% of limestone to give it the correct Portland cement composition. Occasional deposits are found which are suitable to use with no admixtures, or from which the desired proportions may be obtained by mixing two different strata in the same quarry. Several other States, among them the Virginias, Alabama, Colorado, and Utah, have a geological formation similar to that in the Lehigh Valley from which Portland cement is made.

In the Hudson River Valley, near Catskill, New York, are situated large manufactories employing a hard limestone which is nearly pure carbonate of lime, requiring 20% to 25% clay or shale and producing a fine quality of cement. A somewhat similar mixture is used in California and in scattered localities in the Central States.

The marl used for cement is a wet, calcareous earth, in some localities of organic origin from shell deposits, and in other places of chemical formation. There are large cement plants using marl and clay in western New York, Ohio, Indiana, and Michigan.

Chalk and clay deposits resembling those in England are worked in South Dakota, Texas, and Arkansas.

Certain blast furnace slags similar to those used in the manufacture of Puzzolan cement, when combined with a suitable admixture of limestone, produce, after calcination, a true Portland cement.

The waste from the manufacture of soda, when employing the ammonia soda process with suitable raw materials, is substantially a precipitated chalk, and is burned with clay to produce Portland cement.*

In Germany the Alsen and Stettin brands are made from chalk and clay, the Dyckerhoff and Mannheimer brands from limestone and clay, while the Germania and Hanover works use marl and clay. In England

*B. B. Lathbury, *Engineering News*, June 7, 1900, p. 372.

raw materials consist principally of chalk and clay. Belgium manufacturers use chalk and clay, and a Portland cement from natural rock is also manufactured in that country. In France, marl and clay, and chalk and clay, are the chief raw materials for true Portland cements.

The character and proportioning of the raw materials and the processes of chemical combination are discussed by Mr. Spencer B. Newberry in Chapter VI.

The following table illustrates the composition of various classes of materials which are used for Portland cement, and also the resulting analysis of the cement in each case:

Comparative Analyses of Raw Materials and Portland Cements.

		Cement Rock and Limestone.			Limestone and Clay.[4]			Marl and Clay.			Chalk and Clay.*		
		Cement Rock.[1]	Limestone.[2]	Cement.[3]	Limestone.	Clay.	Cement.	Marl.[5]	Clay[6]	Cement.[7]	Chalk.[8]	Clay.[9]	Cement.[10]
Silica	SiO_2	19.06	1.98	19.92	3.30	55.27	21.50	1.75	62.10	22.52	0.35	60.30	22.10
Alumina	Al_2O_3	4.44	0.70	9.83	1.30	28.15	10.50	1.57	20.09	6.69	0.75	11.07	11.32
Iron Oxide	Fe_2O_3	1.14		2.63					7.81	3.54		8.13	
Calcium Oxide	CaO	38.78	53.31	60.32	52.15	5.84	63.50	49.24	0.65	63.82	54.95	4 40	60.76
Magnesian Oxide	MgO	2.01	0.97	3.12	1.58	22.5	1.80	0.44	0.96	0 69		1.27	1.10
Sulphuric Acid	SO_3			1.13	0.30	0.12	1.50	0.15	0.49	0.98		2.50	1.40
Carbonic Oxide	CO_2	32.66	42.94		40.98			39.16			43.17	7.47	1.94
Water	H_2O				8.37				8.00			4.06	
Organic Matter								7.50					
Other Constituents							0.40			1.08	0.85	0.45	1.38

NOTE.—Carbonates in raw materials, given in some of the analyses, have been transformed into oxide.
[1] Cement Rock. Lehigh Valley District, Penn. 21st Annual Report, U. S. Geological Survey. Pt. 6, p. 404.
[2] Pure Limestone, Lehigh Valley District. W. E. Snyder, Analyst.
[3] Lehigh Valley Cement. Booth, Garrett & Blair, Analysts.
[4] Hudson River Valley. Mineral Industry, Vol. 6, p. 97.
[5] W. H. Simmons, Analyst, 22d Annual Report, U. S. Geological Survey, Pt. 3, p. 650.
[6] Shale. Mineral Industry, Vol. 6, p. 99.
[7] Michigan. W. H. Simmons, Analyst, 22d Annual Report, U. S. Geological Survey, Pt. 3, p. 680.
[8] Water, 23%. Analysis from David B. Butler, England.
[9] Estuary Mud. Roughly dried, lost 33⅓%. Analysis from David B. Butler, England.
[10] English Portland Cement. Analysis from David B. Butler, England.

Processes in Portland Cement Manufacture. The method of mixing the materials in preparation for their introduction into the kilns has led to

*The authors are indebted for these analyses of chalk and clay to David B. Butler, of England, who prepared them for this Treatise.

a classification of processes into (1) wet process, and (2) dry process. The former is often subdivided into wet and semi-wet, depending upon the quantity of water added at the time of the mixing.

The *wet process* is employed with soft or wet materials, such as chalk and clay, or marl and clay. The carbonate of lime and the clay are mixed in a vat or wash-mill with a large excess of water. Agitators break up the lumps and so finely reduce the particles that they are held in suspension in the water and flow off over the top of the vat. In another basin the stuff is allowed to settle, the water is drawn off, and the "slurry" becomes hard enough to handle in barrows and then form into bricks to be dried, and finally calcined in stationary kilns.

By using a smaller quantity of water, say 40 or 45%, the settling process and consequent hand-labor is avoided, and the material is made only fluid enough to handle in pumps. After grinding, it may be pumped directly into the rotaries, or, if stationary kilns are used, the pumps throw it to the drying room to be made into bricks. This process is called in England the semi-wet process, but as it is practically the only wet process used in the United States, it is here simply termed the wet process.

The *dry process* was first used in Germany as a result of the substitution of limestone for the chalk of England. The two ingredients are ground and mixed in a dry state. If the kilns are stationary, the mixed material must be moistened with sufficient water to form plastic bricks, which are then dried, but for rotary kilns no water is added, the mixture of dry materials passing, after being ground, directly into the kiln.

Dry Process with Rotary Kilns. The introduction of rotary kilns into new cement plants is universal, while many of the older mills are substituting them for their stationary kilns. Where rock, or rock and clay, form the raw materials, they are mixed and ground, and introduced into the rotary in the form of a dry powder. If marl or chalk furnish the carbonate of lime, the wet process of mixing and grinding is usually employed, as described on page 720, although in a few plants each of these materials is dried when entering the mill, and the operations are similar to those described below for rock mixtures, except that driers and disintegrators are substituted for stone crushers.

The process of manufacturing Portland cement from rock, or rock and clay mixtures, in plants equipped with rotary kilns, consists essentially of crushing the materials, — either separately or after mixing them, — drying, grinding, calcining in the rotaries, cooling, grinding to powder, and packing.

The details of the process will be best understood by briefly describing the typical machinery shown in the illustrations. Various types and makes of grinding machinery will produce similar results, those selected being merely representative.

If two stones of fairly similar texture and each of uniform composition form the raw materials, they may be carefully weighed and thrown together into the breaker. Otherwise, they are treated separately, and mixed just before the grinding which precedes the calcination. A common type of breaker is the gyratory crusher shown in Fig. 78 on page 244, No. 5 or No. 6 being the usual size employed. This reduces the stone to a size varying from dust to about 2½-inch diameter. A further reduction in size to about ½-inch is accomplished in plants of modern design by crackers of the coffee mill type (see Fig. 229), or similar machinery.

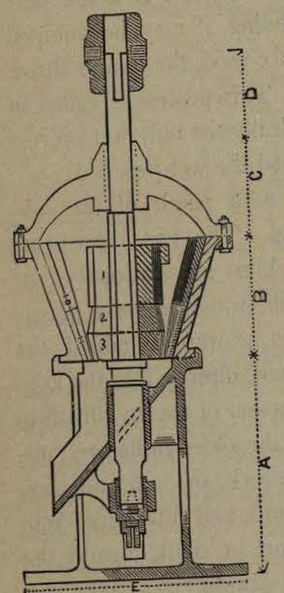

FIG. 229.—Coffee Mill Cracker. (See p. 712.)

Clay, if used, is dried in broken lumps, and then may be pulverized by passing it through a disintegrator consisting of two horizontal rolls, one corrugated or toothed and the other smooth.

An economical form of dryer for clay or stone consists of a long revolving steel tube about 4 feet in diameter, provided with shelves on its interior surface, formed by horizontal Z-bars. The hot gases from the kiln may be made to pass through the tube and meet the raw material.

By treating the two materials separately up to this point, an extremely accurate mixture is obtained by weighing the ingredients in a pair of automatic weighing machines (see Fig. 230), so arranged that one of the pair will not dump until both are charged.

Samples of the two materials are taken, just before mixing, at definite periods throughout the day, and analyzed to determine the correct proportions. A partial analysis showing the quantities of the principal constituents may be all that is necessary except at occasional intervals. The maintaining of correct proportions is one of the most essential elements in the manufacture.

Another grinding of the mixed materials in tube mills, Kent Mills, Griffin Mills, Fuller Mills (pp. 716, 717), or similar machines, to a fineness which will pass a screen having 20 to 30 meshes per linear inch, completes the preparation for the rotary kilns. The actual fineness of the

ground stone at this point is such that 90% to 95% or even a higher percentage will pass a screen having 100 meshes to the linear inch. Fine grinding before burning is one of the secrets of successful manufacture.

The best type of rotary kiln (see Fig. 231) used for calcining dry matetials, consists ot an inclined steel tube from 60 to 200 feet long. The diameter is generally 6 to 12 feet, though occasionally smaller than this t the upper end and tapering to the larger size at a point about one-

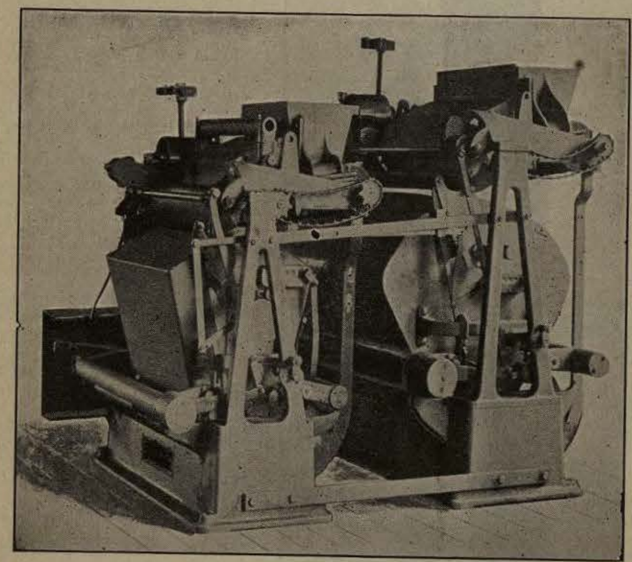

FIG. 230.—Tandem Automatic Weighing Machine. (See p. 712.)

third of its length from the upper end. The lining may be of U-shaped fire-brick in order to present, as a non-conductor of heat, a hollow surface against the shell of the rotary. The lower end of the rotary is closed by a stationary brick wall, and through the center of this passes a pipe which feeds the petroleum, or more frequently the powdered coal which in a separate building is crushed to pea size and pulverized in tube mills, or other pulverizing machines, so that about 90% passes a 100-mesh screen; the finer the coal the greater its efficiency.

The ground stone may be fed into the upper end of the rotary by a spiral conveyor enclosed in a pipe which is water-jacketed so that the material will not cake. The degree of calcination is governed by the supply of raw material, the speed of rotation of the rotary, which rests on rollers geared to a speed-changing device, and the quantity of fuel. If coal is used for fuel, it is fed by a blast from a fan, and the quantity is regulated by a spiral