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“The Rotatory Process of Cement Manufacture.”

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THE subject of this Paper is a method of manufacturing cement that has come into use within the last few years in this country, on the Continent and in the United States, which presents such important advantages over older methods, that, in the Authors' opinion, the complete replacement of these by the new process may be regarded as certain. If this anticipation is realised, the new process will involve a revolution in a great industry, changing it from a somewhat primitive and empirical series of operations to one which depends upon the application of sound mechanical principles; will allow of a large economy in labour and in cost of fuel; and lastly, will ensure the production of a Portland cement better and more regular in quality than that at present manufactured.

In order to give a clear account of the nature and advantages of the new process it is necessary to deal briefly with the chief features of older methods.

MANUFACTURE WITH FIXED KILNS.

Portland cement is made by heating to a clinkering temperature an intimate mixture of calcareous and argillaceous materials. The raw materials may be chalk, clay, limestone, shale or marl, but whatever their nature the two conditions of intimate mixture and exposure to a temperature at which the product is at least plastic are essential. In whatever manner and from whatever substances Portland cement is prepared, the ratio of the basic and acid oxides composing it approximates to that expressed by the equation

all quantities being reckoned in equivalents, not in percentages. In practice the ratio is kept appreciably below 3, that is to say, the amount of lime in the cement is lower than that required to saturate the whole of the silica and alumina by forming tricalcium silicate and tricalcium aluminate therewith. Under present conditions of manufacture this limitation of the lime is necessary for safety because, on account of imperfect and irregular burning, complete union of the acid and basic constituents of the cement cannot be ensured. With a more nearly perfect process of burning the theoretical limits of composition can be closely approached, and a cement not merely stronger but very much safer can be manufactured. When chalk and clay are employed as the raw materials they are usually mixed in a wash-mill with sufficient

water to form a slurry which can be pumped. The water necessary for aiding mixture and allowing transport by pumping has to be removed before the slurry can be burned. In this country drying is generally effected on floors heated by the waste gases of the kilns, which are commonly those known as chamber-kilns. *Fig. 1* represents a chamber-kiln with its drying-floor.

The kiln is a brickwork structure about 16 feet in diameter and 18 feet in height, having a grate at the bottom and opening into a long wide horizontal flue in which is run the slurry to be dried by the waste gases. The fuel used is coke, which is loaded into the kiln interspersed with the dried slurry; the quantity

required is 40 per cent. to 50 per cent. reckoned on the weight of clinker produced. Coke is not only a relatively costly fuel, but is one liable to sudden and artificial fluctuations of price, a tendency highly inconvenient to the cement-maker. The labour needed for loading and drawing the kilns is very heavy, and the clinker produced is far from uniform, often containing much under-burnt material which needs to be picked out before the clinker is ground. A kiln of this class of average size will need 5 days to 6 days for a complete trip, and will not produce more than about 35 tons of clinker per week.

When dry raw materials, *e.g.*, shale and limestone, are used, some form of continuous kiln is generally employed. The materials are finely ground, intimately mixed and damped sufficiently to enable them to be moulded into rough bricks. These are burnt in ring- or shaft-kilns. The ring-kiln of the Hoffmann type is largely used in this country in the manufacture of bricks, but is rarely employed for cement. It is economical of fuel, needing only about 15 per cent. to 20 per cent. on the weight of the clinker produced, but requires a large amount of fairly skilled labour in stacking the bricks of cement material into the chambers of the kiln, and in regulating the firing by feeding fuel into the spaces left between the stacked bricks; it has also to be unloaded by hand. The necessity of regular stacking of the material to be burnt makes the Hoffmann kiln less suitable for treating material such as cement, which becomes deformed when hot, than for burning building-bricks and the like which retain the regularity of their shape.

The Dietsch kiln is a typical shaft-kiln, and is largely and successfully used for burning cement.

As shown in *Fig. 2* it is a continuous kiln, having a feeding-door at the base of the stack, a burning-chamber and a cooling-chamber through which the material to be burned successively passes. It is economical of fuel, using 15 per cent. to 20 per cent. of the weight of the clinker produced, but is costly in labour.

Both the Hoffmann and the Dietsch kilns can be used for wet raw materials, but they require supplementary drying-arrangements by which the slurry may be dried sufficiently to allow of its being moulded into bricks. The amount of fuel necessary for drying is usually somewhat greater than that needed for burning, so that the total amount of fuel required, *viz.*, 35 per cent. to 40 per cent. on the clinker, is not much smaller than that needed for chamber-kilns, but a cheaper kind of fuel can be used, namely, small coal.

The principle of continuous working is so attractive, on account of its economy in fuel and its increase of output per kiln, that it has been embodied in various other forms of kiln. These are in general vertical cylindrical shafts not unlike a running lime-kiln, but usually with a flue or chimney at the upper end and loading-doors at the base of this flue. The clinker is drawn at the bottom where there is usually some kind of removable grate. In one kiln of this class a blast of air is blown in at the base of the kiln. The charge is regulated so that the mixture of coke and cement material is in full ignition at a point about one-third of the way down the kiln, its products serving to heat the raw material in

the upper part, and the hot clinker in the lower part yielding its heat to the incoming air. Kilns of this class are economical of fuel, but as a rule require the use of coke instead of small coal, and need a good deal of skill in loading. The hot plastic clinker is liable to stick to the walls of the kiln, causing the charge to hang; this not only hinders the proper working of the kiln, but also acts on the lining and hastens its destruction. Unless skilfully worked these kilns are apt to yield a good deal of underburnt clinker which has to be picked out.

The quantity of clinker produced by these different classes of fixed kiln varies considerably with local circumstances, but may be stated in round figures as follows :—Chamber-kiln, 35 tons per

week; Dietsch kiln, 70 tons per week; Schneider kiln,¹ 70 tons per week; Hoffmann kiln, 28 tons per week for each chamber.² With all these varieties of fixed kiln the amount of labour needed for handling the raw material and clinker is large, whether the kiln be continuous or discontinuous. Moreover, kilns of the continuous class when wet raw materials are used require an elaborate drying-plant to prepare the raw material before it is fed into the kiln to be burnt. In whatever class of fixed kiln it is produced the clinker is irregular in quality, containing a good deal of imperfectly burnt material; unless this is picked out most carefully sufficient underburnt material remains to impair the quality of the finished cement in a serious degree. Finally the finished cement needs to be matured by storage before it can be used with safety for important work.

MANUFACTURE IN ROTATORY KILNS.

A rotatory kiln for the manufacture of cement consists in its simplest form of a long cylinder of boiler-plate lined with refractory material, inclined slightly to the horizontal, and capable of being rotated by suitable gearing. There is a powerful burner or other suitable source of heat at the lower end, and at the upper end is a conveyor or equivalent device by which the raw material may be fed in. The material is caused to travel down the cylinder by the joint effect of the rotation and the inclination of the kiln, and is systematically heated as it proceeds until at the lower end it reaches a clinkering temperature and falls from the end of the kiln as finished clinker. In 1877 Thomas Russell Crampton, M. Inst. C.E., patented a process for burning cement in rotatory kilns, but appears not to have put his invention on a manufacturing footing. It may be accepted that the earliest form of rotatory kiln which approached practical success was invented in this country by the late Mr. Frederick Ransome, Assoc. Inst. C.E.; this kiln may be regarded as the forerunner of modern rotatory kilns now being erected or at work in England or abroad. Ransome's English patent is dated May 2, 1885, and, in view of the subsequent development of the rotatory process, affords an interesting object of study.

¹ This is a kiln of the continuous cylindrical shaft type last mentioned.

² A ring kiln of fourteen chambers each, having a capacity of 40 tons, will give 560 tons of clinker for a complete round trip, which will take about 10 days. This represents an output of 56 tons per day, or 392 tons per week for the whole kiln, *i.e.*, 28 tons per week for each chamber.

The Ransome kiln, *Fig. 3*, consists of a cylindrical furnace A, set at a slight inclination, carried on rollers, and rotated by worm-gearing B. At the upper end powdered raw material is fed in by the hopper C, and travels down the furnace, meeting burning producer-gas entering by the pipe D. The burnt material falls into the pit E, and any raw material which may be blown back up the furnace is caught in the settling-pit F, whence it can be returned to the hopper.

The inventor states that whereas in ordinary methods of burning cement it has always been necessary "to grind the cement after burning to bring it to the requisite degree of fineness," in his process "by introducing the cement material into the rotating chamber as a fine powder the necessity for grinding the cement after burning is entirely obviated." This idea, which is put forward in his provisional specification, is emphasized in the complete specification, where the following passage occurs. "The slurry is dried, then pulverised, and afterwards sifted to bring it to the degree of fineness required in the sifted cement," also one of the claims of the patent is for a process of manufacturing cement by burning dry powdered raw materials, "so that the cement produced may be used without subsequent grinding." It is abundantly evident that one of the chief objects which Mr. Ransome had in view was the abolition of the costly process of grinding clinker. His claim to accomplish this was made in ignorance of the fact that at the temperature necessary for burning Portland cement the material becomes plastic and sticky, and although it may be in the finest powder before burning, yet it will cohere and form small nodules or lumps when burnt. He also failed to see that systematic heating of the raw material by passing it through the kiln in a direction opposite to that of the burning gases was of fundamental importance, because he suggests introducing the raw material at the end where the burner is situated as an alternative to the correct and rational method of feeding it in at the end remote from the burner. But although in error in these two important respects, the inventor saw clearly that a great saving in the cost of production (largely due to economy in labour) would be effected by a rotatory process, and that the cement made by such a process would be more uniformly burnt than that made in masses in a fixed kiln. In spite of its merits in principle the Ransome process was a complete failure in practice. One of the chief difficulties encountered was the behaviour of the cement clinker in contact with the lining of the kiln. At the hottest part of the cylinder where a clinkering temperature

Fig. 3.

obtained, it was found that the clinker as it formed adhered to the firebrick lining and formed a ring, obstructing the passage of further supplies of raw material. It is not too much to say that the success of the modern rotatory process depends largely on the methods which have been adopted for obviating this difficulty; these will be dealt with in a later part of the Paper. There were other troubles in the Ransome process. The finely-divided raw material was carried by the draught out at the upper end of the kiln and had to be caught and returned. The use of producer-gas without a regenerator scarcely allowed regular attainment of a temperature high enough to burn the clinker completely. When a regenerator was used it speedily became choked with the dust carried away by the draught. The cement obtained was inconveniently quick-setting, for a reason which will be discussed in due course. The burning-cylinder was only about 25 feet long, and this length was insufficient to allow of the economical use of the fuel, and moreover led to the burning out of the tube used to feed in the raw materials at the upper end of the cylinder.

A substantial improvement on the Ransome apparatus was made by Mr. Wilfrid Stokes, who realised clearly that one of the merits of a properly-contrived rotatory process was the economical and systematic use of heat. The waste gases departing from a burning-cylinder, such as Ransome's, contain a large amount of heat, as does the white-hot clinker falling from the lower end of the burning-cylinder. The heat from both sources is effectively utilized in the Stokes process. In order to determine what are the limits of possible economy the quantity of heat needed to burn a given weight of cement may be calculated, the results being applicable not only to the Stokes apparatus, but to the rotatory process generally. For the production of 1 ton of clinker an average quantity of $1\frac{1}{2}$ ton of dry raw material is needed. This will contain about $1\frac{1}{8}$ ton of chalk or limestone, and $\frac{3}{8}$ ton of dried clay or shale. When this mixture is heated, energy is expended chiefly in decomposing calcium carbonate. The energy needed for the decomposition of 1,125 kilograms (about $1\frac{1}{8}$ ton) of calcium carbonate is 478,012 calories. The dehydration of the aluminium silicate in the clay requires the expenditure of a small quantity of energy, but the amount is not accurately known. The reaction of the lime liberated by the decomposition of the calcium carbonate on the silica and alumina of the clay to form calcium silicates and aluminates is probably exothermic, and this supplies a small amount of heat. These plus and minus quantities may be regarded, without serious error, as balancing

each other. It comes about, therefore, that the heat needed to convert $1\frac{1}{2}$ ton of dry raw material into 1 ton of clinker is in round figures 480,000 calories; 60 kilograms of coal having a calorific value of 8,000 calories will furnish this amount of heat, corresponding with a consumption of coal of 6 per cent. on the weight of clinker produced. How nearly this limit may be approached in practice may be usefully considered.

In any properly-contrived continuous process for burning cement the incoming air is used to cool the finished clinker, and the outgoing furnace-gases are used to heat the raw materials. The temperature of the outgoing clinker may be taken at 100°C . (212°F .) and that of the waste gases at 300°C . (572°F .). The heat contained in the outgoing clinker and that in the waste gases are the only losses of energy (other than radiation) from the apparatus. These, together with the energy required to bring about the chemical changes involved in the production of clinker from its raw materials, are a measure of the total amount of heat which must necessarily be expended in producing a given weight of clinker. But if this heat is obtained by the combustion of coal, the air necessary for combustion will constitute the greater part of the waste gases, and the calories carried away by the waste gases will depend on the weight of coal burned, which, in its turn, must suffice to supply these calories. Supposing the coal to contain an average of 80 per cent. of carbon and 5 per cent. of hydrogen the amount of air necessary to burn 1 kilogram will be approximately 11 kilograms. Allowing the usual surplus of 100 per cent., the total weight of air will be 22 kilograms, and, neglecting the ash of the coal, the total weight of the gaseous products of combustion will be 23 kilograms. Calling x the number of kilograms of coal needed for burning 1,000 kilograms (1 ton) of clinker it is evident that the number of kilograms of waste gases will be $23x$. The whole of this has to be heated from 15°C . (60°F .) to 300°C . (572°F .).

Similarly the CO_2 liberated by the decomposition of the calcium carbonate of the raw materials, has to be heated through the same range of temperature. Thus the causes of expenditure of heat which have to be met to produce 1,000 kilograms of clinker are:—

	Calories.
1. For decomposition of 1,125 kilograms CaCO_3 . .	478,012
2. For lost heat in clinker (specific heat $0\cdot2$, temperature 85°C . above that of the air) . . . }	17,000
3. For lost heat in waste gases—	
(a) 495 kilograms of CO_2 from CaCO_3 . . . }	
(b) $23x$ kilograms of products of combustion	$(23x + 495)$
from coal and air (average specific heat	$\times 0\cdot24 \times 285$
$0\cdot24$, temperature 285°C . above that of the	
air) }	

The whole of this heat has to be provided by x kilograms of coal having a calorific value of 8,000 calories. Hence—

$$8,000 x = 17,000 \text{ (heat in clinker)} + 478,012 \text{ (heat needed to decompose CaCO}_3\text{)} + (23 x + 495) \times 0.24 \times 285 \text{ (heat in waste gases).}$$

$$\therefore x = 82.3 \text{ kilograms,}$$

i.e., 8.23 per cent. on the weight of the clinker produced.

This figure, if increased by an allowance of 20 per cent. for radiation, gives 9.88 per cent. as the minimum consumption possible under the conditions set forth above. The best results hitherto attained in practice have required more than double this amount. When wet raw materials are used, the evaporation of their water requires a further consumption of fuel. This may be calculated with a fair degree of accuracy. Slurry, in the condition in which it is pumped, usually contains about 40 per cent. of water. For every $1\frac{1}{2}$ ton of dried slurry (corresponding with 1 ton of clinker) there would be 1 ton of water (say 1,000 kilograms). The heating of this quantity of water from 15°C. to 100°C. and its evaporation from 100°C. requires $1,000 \times 85 + 1,000 \times 537 \text{ calories} = 622,000 \text{ calories}$. Assuming the temperature of the waste gases to be, as before, 300°C. , there must be added to this water-vapour a further quantity of $1,000 \times 200 \times 0.48 \text{ calories} = 96,000 \text{ calories}$. The total increment to be met is therefore 718,000 calories. It follows that when wet slurry (containing 40 per cent. of water) is used as the raw material, the total amount of heat needed for the production of 1 ton (1,000 kilograms) of clinker will be:—

	Calories.
1. For decomposition of 1,125 kilograms CaCO_3	478,012
2. For lost heat in clinker (specific heat 0.2, temperature 85°C. above that of the air)	17,000
3. For lost heat in waste gases—	
(a) 495 kilograms of CO_2 from CaCO_3 (specific heat 0.24, temperature 285°C. above that of the air)	33,858
(b) 1,000 kilograms of H_2O from 15°C. to 300°C.	718,000
(c) $23 x$ kilograms of products of combustion from coal and air (average specific heat 0.24 , temperature 285°C. above that of the air).	$23 x \times 0.24 \times 285$

The whole of this heat has to be provided by x kilos of coal having a calorific value of 8,000 calories. Hence—

$$8,000 x = 478,012 \text{ (heat needed to decompose CaCO}_3\text{)} + 17,000 \text{ (heat in clinker)} + 718,000 \text{ (heat in steam)} + 33,858 \text{ (heat in CO}_2\text{ from CaCO}_3\text{)} + 23 x \times 0.24 \times 285 \text{ (heat in products of combination).}$$

$$\therefore x = 194.0 = 19.40 \text{ per cent. on the weight of the clinker.}$$

Allowing as before 20 per cent. of this calculated value to cover loss by radiation, there results 23·28 per cent. of coal reckoned on the weight of the clinker as necessary for burning raw materials containing 40 per cent. of water.

A sensible economy is secured if the waste gases escape at an appreciably lower temperature, *e.g.* 200° C. Under these conditions the calculated minimum quantity of fuel is 17·01 per cent. on the weight of the clinker produced. The distribution of heat expenditure may be usefully stated in tabular form; loss by radiation is in this case omitted.

A.—DRY RAW MATERIALS.

	Per cent.
Heat necessary for decomposition of calcium carbonate . .	72·6
„ lost in clinker	2·6
„ „ waste gases	24·8
	<hr/> 100·0

B.—WET RAW MATERIALS.

(Slurry containing 40 per cent. of water.)

	Temperature of Waste Gases 300° C.	Temperature of Waste Gases 200° C.
	Per cent.	Per cent.
Heat necessary for decomposition of calcium carbonate	30·8	35·1
Heat lost in clinker	1·1	1·2
Heat necessary to evaporate water and to heat water vapour to temperature of products of combustion . }	46·3	49·3
Heat lost in products of combustion including CO ₂ } from CaCO ₃ }	21·8	14·4
	<hr/> 100·0	<hr/> 100·0

A glance at these figures will show the enormous advantage in fuel consumption possessed by the user of dry raw materials. This advantage is so considerable that it would appear rational to avoid any addition of water to existing raw materials. But in English practice this addition is deliberately made; moist chalk and clay are washed to a slurry containing as much as 40 per cent. to 50 per cent. of water, all of which has to be dried off before the material can be burned. The cause of this procedure is to be found partly in the belief that complete admixture cannot be obtained without the use of water, and partly in the imperfections of most of the older types of drying-apparatus. The presence of flints in the chalk is also a good reason for washing. The full discussion of this question is

outside the limits of this Paper, and it is sufficient for the present purpose to draw attention to what is on the face of it an anomalous state of things.

In the Stokes process precautions were taken to effect a considerable economy in fuel. The whole apparatus was particularly well thought out, and its failure to realize the expectations of its inventor is greatly to be regretted, the more so as it delayed for nearly ten years a much-needed improvement in an important industry, and allowed the centre of interest to shift from this country, which is the birthplace of the rotatory process, to the United States, which is its country by adoption and where it has developed and prospered. The plant is shown in *Fig. 4*. A is the burning-cylinder about 35 feet long and 5 feet in diameter, constructed of steel plates and mounted on two sets of live rollers resting on a cast-iron cradle, with freedom to allow for expansion and contraction. The cylinder is driven by a small engine and spur-gearing; it is lined with refractory bricks. The waste gases from the burning-cylinder pass through the drying-drum B about 40 feet long and 12 feet in diameter. At each end of the drum is a roller-path resting on supporting wheels, and the drum is slowly rotated by worm-gearing driven by a small engine. The slurry is fed on to the outside of the drum by means of a dipping-arrangement which delivers a definite quantity of slurry from a long trough (not shown in the figure) above the drum. The slurry adheres to the

drum and is dried by the time the drum has nearly completed a revolution, when it is scraped off by a series of chain scrapers driven along the top of the drum and delivered into the feed-shoot of the burning-cylinder. The clinker emerging from the lower end of the burning-cylinder falls into the cooling-cylinder C, 35 feet long and 5 feet in diameter. This cooling-cylinder is of steel, unlined but provided with gills which aid in abstracting heat from the clinker to be cooled. The drying-drum, burning-cylinder, and cooler are arranged so that the material passes down the series by gravity. The burning-cylinder is heated by gas from a producer; the necessary air is supplied through the cooling-cylinder, the heat from the outgoing clinker being thus regenerated.

The above description has been supplied to the Authors by Mr. Wilfrid Stokes, for whom they made certain investigations when the apparatus was being designed. Numerous difficulties, chemical and mechanical, had to be dealt with in the course of this work. It is not too much to say that Mr. Stokes's ingenuity and resource enabled him to overcome almost all these, but certain obstacles appeared practically insuperable. It was necessary in the first place to establish at what rate drying could be effected with the waste gases in the form of dryer selected. Next it had to be recognised that the mixture of chalk and clay proper for the manufacture of cement by the old process was not suitable for the new method. This is because the ash in solid fuel (*e.g.*, coke) consists chiefly of silica and alumina, and may be properly regarded as acting like the clay; therefore, there must be enough calcium carbonate in the slurry to unite with these bodies if a normal cement of proper composition is to be produced. If such a slurry be burned with a fuel which contains no ash, such as producer-gas, the content of lime in the resulting cement will be unduly high. In the third place it was found that the cement, being almost free from sulphates (which are mainly derived from the coke or other solid fuel), was abnormally quick-setting; the regulated addition of gypsum to lengthen the setting-time was therefore necessary. But these were small matters compared with the difficulty of maintaining a sufficient and uniform temperature in the burning-cylinder. Finally, and this was the worst trouble to be met, the provision of a satisfactory lining for the burning cylinder appeared impossible of attainment. When ordinary fire-bricks were used they were speedily attacked by the clinker which corroded and destroyed them, and was itself spoiled. A basic lining naturally suggested itself, but magnesia bricks were

dear and conducted heat over-readily. Bricks of bauxite were prepared, but were found to be weak and friable, thus failing from mechanical defects although fairly satisfactory chemically. The manner in which this lining difficulty has since been overcome by other inventors will be described in due course.

The ideas underlying the Ransome process took root in the United States and bore fruit there. With characteristic energy and determination American inventors began to try to make cement with rotatory kilns and to improve upon the unsuccessful attempts of their predecessors. In this task they were much aided by the fact that they could use petroleum—a fuel too dear to be employed here. The ease with which the temperature of the kiln could be controlled when a jet of burning petroleum was the source of heat allowed many somewhat crude attempts to reach a qualified success. But for a world-wide industry petroleum is not a practically attainable fuel; even in America it is not so generally available as coal, and moreover its price is artificial and is controlled by a few hands. The abolition of the necessity to use petroleum has made the rotatory process adaptable for all industrial countries.

In the autumn of 1898 one of the Authors visited the United States to inspect and report upon a rotatory process in use at the works of the Atlas Cement Company at Northampton, Pennsylvania, and had the advantage of conferring with the joint inventors, Mr. E. H. Hurry and Mr. H. J. Seaman. The Atlas Cement Company's works form probably the largest cement-manufactory in the world; and the whole of the plant is on the rotatory system devised by these gentlemen. There are running at present fifty-one kilns with an average output of between 8,000 barrels and 9,000 barrels per day (*i.e.*, between 8,000 tons and 9,000 tons per week), a quantity four times the output of most works which are regarded as large on this side of the Atlantic. The size of the works is of course interesting merely as showing that the process is in no sense experimental, but is already at work on a huge scale. When it is stated that the Atlas Cement Company is now erecting another plant of forty-eight kilns which will almost double its output, it may fairly be concluded that the process is economical and remunerative.

The raw materials used by the Atlas Cement Company are a calcareous shale containing about 70 per cent. of calcium carbonate and a limestone containing about 93 per cent. of calcium carbonate, the two being mixed in such proportions as to produce a normal

clinker. The shale and limestone are crushed in Gates crushers, passed through rotatory sieves, dried in a rotatory drier and ground in Huntington mills to a fineness of 10 per cent. on a 100×100 mesh sieve. The dry well-mixed powder is carried by conveyors to stock-boxes above the feeding ends of the rotatory kilns; the capacity of these boxes is sufficient to supply the kilns

Fig. 5

with raw material for 48 hours, thus allowing the pulverising plant to be shut down over Sunday while permitting the kilns to run on. This is necessary because the essence of the rotatory process is its continuous working day and night throughout the year.

In the Hurry-Seaman plant, Fig. 5, the kilns are rotating

cylinders 60 feet in length and 6 feet 6 inches in diameter at the lower end and 5 feet in diameter at the upper end, and inclined $\frac{7}{8}$ inch per foot; they are carried on rollers and rotated by suitable gearing at a rate varying according to the conditions of burning between nine and thirty-two revolutions per hour. At the lower end is a burner fed with powdered coal, shown diagrammatically in the figure, which is injected by means of a blast of air. The burning coal-dust produces a blast-flame of such power as to raise the lower part of the kiln to a clinkering temperature. From the lower end the temperature gradually diminishes to the upper end, from which the comparatively cool gases escape into a chimney. The raw materials entering at the upper end are gradually raised in temperature as they descend towards the lower or furnace end. The rate of descent is regulated by the angle of inclination of the cylinder and by its speed of rotation, and is so adjusted that when the raw materials reach the "clinkering-zone," *i.e.*, the length (about 10 feet) at the lower end of the cylinder which is maintained at a clinkering temperature by the action of the blast of coal-dust, the carbonate of lime has been decomposed, the clayey material dehydrated and interaction between the lime and the silica and alumina has begun. The completion of this interaction and the production of clinker then occur in the clinkering-zone and fully burnt clinker passes out at the lower end of the cylinder.

Although this description will serve to give a general idea of the construction and operation of the kiln proper it does not include certain details which are of the highest practical importance and make all the difference between successful use of the rotatory system and failure partial or complete. The method of heating the kiln is one of these details. The coal used at the Atlas Cement Works at the time of the Authors' visit had the

	Per cent.
Composition	

Volatile carbonaceous matter Fixed " " Ash Moisture ,	Per cent. 30·42 60·30 8·38 0·90
	<hr/> 100·00

As bought, in the form of slack, it contained more moisture than is shown in the analysis, which is that of the fuel ready for use. The slack is dried in a rotatory drier, ground in Huntington mills and conveyed to stock-boxes arranged over the burner ends of the kilns. Although this coal is cheap and suitable, yet other kinds, even anthracitic coal, are equally applicable. When

anthracite is used its hardness somewhat increases the work of grinding, but when finely powdered it makes an excellent fuel. The burner itself is essentially an air-injector carrying in the fine dry coal-dust which has been previously pushed by a screw conveyor into the region of the pull of the injector, and is kept well agitated, so that it may the more easily distribute itself when mixed with the injected air and that which is pulled in. The invention of an efficient burner was accomplished only after numerous experiments; the use of such devices as fans blowing powdered coal along the inlet tube to the kiln and similar fairly obvious contrivances does not produce the uniform and easily controlled flame which is essential to the satisfactory burning of cement clinker.

The lining of the kiln is another matter which needs special mention. In order to explain the cause of the difficulties encountered when ordinary firebrick lining is used, and to indicate the nature of the remedy which has been found, a short excursion into the chemistry of refractory materials is requisite. The ordinary material used for lining furnaces is firebrick, which is substantially composed of silica and alumina; it contains, as minor constituents, oxide of iron, magnesia, and alkalies. The percentages of the chief constituents may range from 75 per cent. of silica and 20 per cent. of alumina, to 55 per cent. of silica and 40 per cent. of alumina. Such bricks behave as an acid substance towards Portland cement clinker, which, being rich in lime, is a basic material. The acid brick and the basic clinker flux together and unite to form a fusible mass similar to blast-furnace slag. This action is inevitable at a clinkering temperature, and, if allowed to proceed, gradually causes the destruction of the firebrick lining and the deterioration of the cement clinker which is contaminated by the slag-like product of its action on the firebrick. Many attempts have been made to remove these inconveniences. As alumina acts as a weaker acid than silica, bricks relatively rich in alumina have been employed. The following analysis gives the composition of a brick of this class:—

	Per cent.
Silica (Si O_2)	55.82
Alumina (Al_2O_3)	37.98
Ferric oxide (Fe_2O_3)	4.02
Lime (Ca O)	Nil.
Magnesia (MgO)	0.78
Soda (Na_2O)	0.88
Potash (K_2O)	0.37
	<hr/> 99.85 <hr/>

But this brick is still strongly acid and is severely attacked in practice. In order to prevent the clinker attacking the lining the latter must be basic. No better form of basic lining can be conceived than one composed of cement clinker itself; obviously it must be without action on cement materials clinkered in contact with it. But it is not a convenient material of which to make bricks with which the lining may be constructed *per se*. A process by which a protective coating of clinker can be applied to an existing lining of firebrick would meet the requirements of the case exactly. This process has been worked out by Messrs. Hurry and Seaman. It is executed in the following manner:—A coating of common salt is applied to that part of the firebrick lining of the kiln which is exposed to a clinkering temperature. The kiln is then heated and the raw cement-material is introduced into the kiln and raised to a clinkering temperature. At this temperature it is plastic, and adheres to the heated surface, on to which it is beaten or pressed down to form an adherent protective coating. The junction between the firebrick and the coating of clinker is protected from the full clinkering temperature by the thickness of the clinker coating, and corrosion of the firebrick by the clinker is prevented. The use of salt to form a sticky surface to which the clinker adheres in the first instance, though advantageous, is not necessary; if the use of salt be dispensed with, the bare firebrick lining is heated to a high temperature, and to it is applied an adherent coating of clinker, which serves as an effectual protection of the junction of the two materials from further fluxing. This simple and beautiful device has changed the entire aspect of cement manufacture in rotatory kilns. It has abolished the whole of the difficulties which have arisen from the destruction of the lining, and has made possible the use of ordinary firebricks, which are cheap and good non-conductors of heat in place of expensive magnesia bricks which conduct heat too freely and are, moreover, liable to crack. By the use of the air-injector coal-dust burner, and by the provision of a basic coating for the hottest part of the kiln, a uniform and high temperature can be maintained which produces clinker of excellent quality. At the time of the Authors' visit to the Atlas Works samples were drawn direct from the mouth of the kiln and found to be of a quality hardly approached by the best clinker made in any fixed kiln; moreover, the quality was uniform. The important advantage accrues that the clinker requires no picking, and one large source of difficulty and expense occurring in the older process disappears. The further course of the clinker as it leaves the burning-cylinder is as follows. The

clinker drops from the burning-cylinder into a second rotating cylinder, see *Fig. 5*, about 30 feet long and 3 feet in diameter, revolving about six times as fast as the burning-cylinder. This is lined with firebrick, 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 regenerated. 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 on to 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 hazel nut. 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-vapour 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. The finished clinker falls into trucks each having a capacity of 10 tons, which are moved by a traverser and elevator to the pulveriser-building, where the material is tipped into iron stock-boxes above the pulverisers. The clinker is then slightly warm to the hand and moist, but not wet. The water lodges in the small interstices of the clinker and serves a purpose to be explained later. It might be supposed at first glance that cement clinker would be injuriously affected by this wetting, but a little consideration will show the reverse to be true. It is well known that cement aerated by storage and turning over is improved not merely in soundness but in strength. This improvement is due to the hydration of those unsaturated lime compounds whose presence is a standing source of instability and weakness. However perfectly the raw materials may be mixed and burned, a certain amount of these unsaturated lime compounds is present. By the process here described these are automatically and systematically provided with a sufficiency

of water (readily controllable) for their saturation. The peculiar nature of the clinker with its numerous interstices favours the lodgment of this small quantity of water without rendering the clinker wet as a whole. When this clinker is ground no clogging of the mills takes place, and the small amount of water is distributed evenly throughout the finished cement and slakes any unsaturated lime compounds. In this way the same object (*viz.*, maturing) is effected rapidly, cheaply and perfectly, which is slowly and expensively brought about by the old cumbrous method of turning over and exposing the finished cement. The quality of the cement may be judged from the results of the Authors' tests and analyses given below:—

<i>Fineness.</i> —	15½ per cent. on 120 × 120 sieve
	3¾ „ 76 × 76 „
	½ „ 50 × 50 „
	Few nibs on 25 × 25 „

Setting-Time.—Over 7 hours.

Tensile Strength (1 inch × 1 inch section).

Neat Cement.		3 Sand, 1 Cement.	
7 days.	28 days.	7 days.	28 days.
Lbs.	Lbs.	Lbs.	Lbs.
640	820	260	370
640	820	240	370
620	810	230	370
610	800	220	360
600	780	210	360
590	770	210	330
Average pounds}	800	228½	360

Colour good. Faija pat, tested in moist air and warm water for 24 hours, satisfactory.

Deval Tests (1 inch × 1 inch section).

3 Sand, 1 Cement, by Weight.			
2 days hot.	7 days cold.	7 days hot.	28 days cold.
310	300	340	390
260	280	325	380
215	270	300	370
Average pounds}	283½	321½	380

Bauschinger Tests.—By this means the alterations in length of a test-bar of cement, 100 millimetres long, are determined with an accuracy of $\frac{1}{200}$ millimetre. The results are stated in units of $\frac{1}{100}$ millimetre.

	<i>Wet Bar.</i>	<i>Dry Bar.</i>
1 day	+ 1.5	— 7.0
7 days	+ 3.5	— 9.5
28 days	+ 4.5	— 13.5
	+ indicates expansion;	— indicates contraction.

These alterations are such as occur with Portland cement of good quality, which expands slightly when kept in water and contracts slightly when kept in air.

	<i>Analysis.</i>	Per cent.
Silica (SiO_2)		20.36
Insoluble residue (sand and clay)		0.44
Alumina (Al_2O_3)		7.26
Ferric oxide (Fe_2O_3)		3.24
Lime (CaO)		61.90
Magnesia (MgO)		3.10
Sulphuric anhydride (SO_3)		1.36
Carbonic anhydride (CO_2)		0.33
Water (H_2O)		1.97
Potash (K_2O) } and loss		0.04
Soda (Na_2O) }		
		100.00

The composition of the sample is normal for Portland cement of good quality.

To complete this sketch of the Hurry-Seaman system it may be said that the stock-boxes for the clinker have a capacity for 48 hours' output, allowing the grinding-plant to be stopped over Sunday, and from these it passes to mills, from which it is conveyed mechanically to store-bins. It is ground so as to leave between 8 per cent. and 10 per cent. of residue on a 100×100 mesh sieve. Before it is sent out it is mixed by screw mixers with a small quantity of plaster of Paris to lengthen its setting-time, and is packed with as little hand-labour as possible. Thus from the tipping-wagons coming from the quarry to the final bags or barrels the material is untouched by hand, and passes automatically and continuously through all the stages needed to convert the rough limestone and shale into finely ground, sound and well-matured Portland cement.

It is convenient to take one of the plants in use at the Atlas

Works as a unit, in order to describe the apparatus needed for a given output on the rotatory system, viz., 2,800 tons per week. A battery of fourteen kilns, contained in a single building, may serve as this unit. The 14 kilns have 14 burners and preliminary coolers, 7 crushing-rolls and 7 final coolers. There are 4 Gates crushers and 1 revolving dryer for the raw materials, and 9 Huntington mills for reducing the raw materials to fine powder. The coal requires 1 revolving dryer and 4 Huntington mills. The clinker is ground in 30 Huntington mills. The grinding-apparatus is driven by an engine of 2,500 HP., and the kilns, coolers, and subsidiary apparatus are driven by an engine of 300 HP.; a duplicate of this engine serves as a standby to ensure continuous working of the kilns and coolers. This provision of power and of grinding-apparatus is probably larger than is absolutely necessary, and the whole plant is of very heavy and substantial build. A smaller margin might be used, and it is possible that this is the case with that portion of the works finished since the Author's visit, but it may be taken as approximately accurate that the entire plant of this one works is nearly four times the size given above. The magnitude of the undertaking may be understood from these figures. Its economy may be gathered from the following data relating to cost of materials, fuel and labour.

The cost of the process falls under the following heads:—

COST OF PRODUCTION OF 1 TON (2,240 LBS.) OF PORTLAND CEMENT.

	Cost per Ton of Cement.	
	s.	d.
Raw materials delivered at mill	1	9½
Fuel for power (20 per cent. of clinker produced) at 6s. 9½d. per ton	1	3½
Fuel for burning (30 per cent. of clinker produced) at 7s. 7½d. per ton	2	2½
Labour (average 36s. per week)	3	0
Repairs, lubricants, etc.	2	11½
Superintendence, laboratory and mill office expenses .	1	1½
	<hr/>	<hr/>
	12	5½

159 men suffice for a 14-kiln plant producing 2,800 tons per week, and of these 118 are unskilled labourers.

For the sake of comparison the approximate cost of the process at average ordinary English prices for fuel and labour may be computed, taking coal for power at 15s. per ton, coal for burning at 10s. per ton, labour per man per week 24s.

	Cost per Ton of Cement.	
	s.	d.
Raw materials delivered at mill	1	9 $\frac{1}{2}$
Fuel for power (20 per cent. of clinker produced) at 15s. per ton	3	0
Fuel for burning (30 per cent. of clinker produced) at 10s. per ton	3	0
Labour (average 24s. per week)	2	0
Repairs, lubricants, etc.	2	11 $\frac{1}{2}$
Superintendence, laboratory and mill office expenses .	1	1 $\frac{1}{2}$
	<hr/> 13 11 <hr/>	

These figures may be compared with the cost of production of Portland cement by the older process in the Thames and Medway districts under favourable conditions :—

	Cost per Ton of Cement.	
	s.	d.
Raw materials delivered at mill	1	9
Coal for power (17 $\frac{1}{2}$ per cent.) at 15s. per ton	2	7
Coke for burning (43 per cent.) at 15s. per ton	6	7
Labour	4	9
Repairs, lubricants, etc.	2	11
Superintendence and expenses	0	8
	<hr/> 19 3 <hr/>	

The chief items in which saving is effected are cost of fuel and labour. The amount of fuel for burning is 30 per cent. on the weight of the clinker produced as against at least 40 per cent. by the old process, and the cost of this fuel is 3s. per ton as against 6s. per ton by the old process. But apart from the question of economy the cement is superior in quality to the product of fixed kilns, and if it had no other merit should appeal to all members of the Institution who are responsible for large undertakings in which concrete is a chief material.

The rotatory method as carried out at various American works and at several on the Continent, details of which are in the Authors' possession, is a very different thing from the efficient and economical Hurry-Seaman process. In all, the main idea has been to use a rotatory kiln and thus obtain a large output per unit of plant and to save labour. But these desirable objects have been very imperfectly attained. In the United States the kilns are generally heated by oil,¹ which is a convenient

¹ Since this Paper was written, the use of coal-dust has extended and that of oil has greatly diminished; the difficulties in the way of employing coal-dust, however, still remain.

and efficient fuel, and readily yields a powerful blast-flame when blown into the kiln by air or steam. Its cost, however, is high, about 3 cents per gallon, or, say, £1 15s. per ton as against coal at 10s. per ton. The cost with oil-burning may be put down at 8s. 6d. per ton of clinker as against 3s. per ton for coal. In this country of course the use of oil would be still more costly. In no works with which the Authors are acquainted is powdered coal being used smoothly and successfully. Several are attempting to employ it, but with mediocre success. The usual and obvious method is to blow the powdered coal in with a fan, a method of feeding which is far less regular than that secured by a properly-contrived injector. In consequence of this the temperature is less controllable, and unburnt fuel may even be driven far up the kiln. As a result much underburnt material is produced, and the lining of the kiln is irregularly heated and occasionally portions are carried away. The clinker thus contaminated is no better than that prepared in the old-fashioned fixed kilns, and of course on account of its small size is impossible to pick. In a few plants producer-gas is used instead of coal or oil, thus reverting to the Ransome and the Stokes processes. There is some difficulty in obtaining a sufficiently high temperature with producer-gas alone, which, for its economical use, requires the employment of regenerators; also gas from a single producer fluctuates much in quality, and the burner needs constant control. If this difficulty is overcome by the use of a gas-holder fed from several producers the sensible heat of the gas is lost. Water-gas would probably work better, but its cost is too high. There is no fuel so economical and manageable as powdered coal, but its use is only practicable with a well-devised burner. The crude plan of blowing in coal-dust and air with a fan is only an elementary attempt to solve the problem.

In no plant other than that at the Atlas works with which the Authors are acquainted, or of which they have been able to obtain information, is a satisfactory lining in use. The best unprotected lining is certainly magnesia bricks; these require a backing of fire-brick or loam to prevent over-heating of the shell; even then the bricks only last a few months, and their cost is excessive. At most works a brick containing a good deal of alumina, similar to that the analysis of which is given on p. 19, is used. This is corroded freely and repairs are numerous and heavy; indeed with these bricks, if the temperature runs up unduly, quantities of slag are formed, pouring out of the kiln and representing so much spoiled lining and cement. Here and there has been a partial recognition of the

fact that the ideal lining would be one of cement clinker, but nowhere outside the Atlas works have the conditions been realised necessary for preparing an effective protective coating of clinker. In only one works within the Authors' knowledge is a workable process employed for cooling the clinker. Even in this the cooling process is merely a repetition of that used successfully by Mr. Stokes ten years ago, consisting of a rotating iron cylinder having shelves to raise and let fall the clinker, and through which air is allowed to pass. The crushing, watering and cooling the clinker described on p. 21 are practised in the Hurry and Seaman process alone. In most works the white-hot clinker is suffered to fall from the end of the burning-cylinder on to the floor, and is then laboriously shovelled into iron barrows, wheeled away and stacked in heaps to allow it to cool sufficiently to be ground. This may take as much as a week. In some cases the shovelling is dispensed with by carrying the hot clinker away by conveyors, but even then re-handling from the cooled heaps is necessary. There appears to have been no attempt made, save in the Hurry-Seaman process, to hydrate the unsaturated lime compounds by the regulated addition of water, thus to prepare a fully-matured cement without aeration.

The foregoing remarks apply equally to the rotatory process as performed on both wet and dry materials, but there are certain points in the use of the former which merit separate discussion. At the Atlas works dry raw materials alone are employed, and on the occasion of the Authors' visit it was considered necessary to examine a typical plant using wet raw materials in order to ascertain what modification might need to be introduced to adapt the rotatory system to English requirements having regard to the fact that wet raw materials are commonly used in this country. With this object in view the works of the Bronson Portland Cement Company at Bronson, Michigan, were visited. This is a small works, but well arranged and producing excellent cement. The raw materials are a calcareous marl which is dug from a marsh by a steam shovel worked from a barge; as soon as the marl is dug out the trench fills with water and the barge can proceed. An indurated clay is used as the argillaceous constituent, but can be washed with the marl to form a slurry. The slurry prepared from these materials contains about 40 per cent. of water and is in all respects comparable with the slurry made in English works save that its content of lime is lower—a necessity when an ashless fuel is to be used. It is pumped direct into the upper end of a rotatory kiln (*Fig. 6*) and is there dried and burned at a single operation.

The upper end of the kiln has no firebrick lining, but is provided with shelves by which the wet slurry is lifted and from which it drops as it proceeds down the kiln. It is well known that slurry, when spread on a drying-floor, consolidates into lumps of considerable mechanical strength. If any action of this sort occurred in the rotatory kiln it is evident that the lumps would not under ordinary condition of working become fully clinkered, and that, if by lengthening the clinkering-zone they were successfully clinkered, they would emerge as large tough hard masses needing crushing before they could be ground, instead of small pieces of uniform size fit to go straight to the grinding-mills. To get over the difficulty it would probably be necessary to dry the slurry in a separate cylinder and powder it roughly before introducing it into the kiln proper. Actual examination of a plant working on those materials showed that no difficulty of the kind occurs. The slurry in the act of drying is so broken up by being turned over and lifted and dropped that it forms small nut-like

Fig. 6.

pieces perfectly well-fitted for burning to clinker. As soon as it has reached this condition it proceeds down the kiln and passes through the same steps of decarbonation, dehydration and clinkering which have been described above. At Bronson the kilns are 60 feet long and 6 feet in diameter. The temperature of the waste gases is 316°C . The fuel used is petroleum, and no difficulty is experienced in obtaining a high and uniform temperature. The lining trouble is met by the use of magnesia bricks at the clinkering-zone. They are effective, but are costly and need a good deal of repairing. There is no attempt to cool the clinker, which is allowed to lie in heaps until cool enough to go to the mills. The output per kiln is 120 tons per week. Another works using wet raw materials in a rotatory kiln is the Hemmoor Portland Cement Fabrik near Hamburg. The slurry, containing about 40 per cent. of water, is fed in at the upper end and dries without tending to form large masses. The fuel is powdered coal driven in by a fan. The hot clinker is received in an iron cylinder with internal ribs through

which passes air to the burner. No crushing or watering of the clinker is performed. The output of the kiln is 200 tons per week, and the consumption of coal about 30 per cent. on the weight of the clinker.

These two examples of a plant using wet raw materials will serve to introduce the question whether it is necessary for their economical treatment to increase the length of the burning-cylinder. The matter is of present importance because extensive works are now being erected in England to handle wet raw materials. It may be noted that a typical kiln burning dry raw materials is 60 feet long and has an output of 200 tons per week. If this could be worked with the calculated minimum quantity of fuel, viz., 8.23 per cent., the calculated temperature of the waste gases would be 300°C . In practice it is found that as much as 30 per cent. of fuel is required, i.e., 72 per cent. of the total heat goes to waste. From this it can be computed that the temperature of the waste gases with this consumption of fuel will be $1,085^{\circ}\text{C}$. = $1,985^{\circ}\text{F}$., and that these gases at this temperature will suffice to dry the slurry necessary to produce 1 ton of clinker, even if it contains as much as 61 per cent. of water, assuming that the waste gases have a temperature of 200°C . It must be remembered that a slurry containing 61 per cent. of water contains more than twice as much water per unit of dry material as one containing 40 per cent. of water, and that the extra quantity of heat needed to evaporate this and provided by the use of 30 per cent. of fuel (reckoned on the clinker) is enormous. As shown on p. 13, the quantity of fuel strictly necessary for drying and burning slurry containing 40 per cent. of water is no more than 17.01 per cent. reckoned on the clinker. By calculation, supposing the burning and drying to take place in two distinct stages, the temperature of the gases passing from the burning- and heating-zone to the drying-zone is 833.5°C . = $1,532^{\circ}\text{F}$.; seeing that the temperature at the clinkering-zone will not exceed $1,500^{\circ}\text{C}$. = $2,732^{\circ}\text{F}$., it is evident that the quantity of heat needed for mere drying is very large. Certain practical deductions follow from these considerations. In the first place it is clear that the burning of dry raw materials under conditions at present obtaining in practice is exceedingly wasteful, and attempts should be made to approach the calculated minimum expenditure of fuel by lengthening the kiln and feeding proportionately faster. It is possible that these experiments might be unsuccessful because the low-temperature heat (under 833.5°C .) might not be absorbed with fair efficiency from furnace-gases passing through a cylinder of large sectional

area. If this temperature were lowered by the admission of more than 100 per cent. excess of air (the quantity assumed in the foregoing calculations) the efficiency would drop. Next it may be said that under present conditions, as defined by practice and quite irrespective of theoretical considerations, the proportion of coal needed to burn dry raw materials to clinker, viz., 30 per cent., is the same as that necessary to treat wet raw materials containing 40 per cent. of water. Moreover, this quantity of water may be doubled and yet remain within the calculated limits defined by the percentage of coal consumed. Obviously, however, it will be wise to restrict the proportion of water to as low a point as possible, *e.g.*, 35 per cent., because in the event of any irregularity of feed of raw materials or of injection of fuel, a sufficient margin will exist to ensure that the clinker emerges properly burned. Seeing that the raw materials in the act of becoming clinker are enhanced in value about 300 per cent., any failure in their conversion is a matter of serious commercial importance.

That an additional length of kiln is needed to dry normal raw materials containing 40 per cent. of water is obvious. At the end of a 60-foot kiln the temperature of the exit gases will not be lower than 800° C. when dry raw materials are used. To pick up the heat involved in a drop of temperature from this to 200° C. will need an extension of the kiln, which extension may be as much as one-third its original length. Thus it may be found necessary to construct kilns 85 feet to 90 feet long for wet raw materials, if the same output per kiln is to be obtained. Kilns actually in operation on wet raw materials are commonly about 60 feet long, but their output is below what may be termed the normal output of a kiln using dry raw materials, viz., 120 tons to 150 tons, instead of 200 tons per week. Recently, however, kilns 90 feet long have been made. The limit to the length of the kiln, given a sufficiently powerful burner, appears to be set only by mechanical considerations. A revolving steel tube with a heavy lining and charge may prove difficult to support satisfactorily when its length approaches 100 feet and its expansion may be inconveniently great. Probably it will be found that with wet raw materials a length of 20 feet to 30 feet additional to that known to be suitable for kilns using dry raw materials will prove economical and effective. Direct experiment is, nevertheless, highly desirable.

The results of the Authors' study of the rotatory process set forth in the foregoing pages may be summarised as follows:—

1. The method is so notably superior in economy and in the quality of the product to older processes that it is likely to supersede them in Europe as completely as it has already done in the United States.

2. That although rotatory kilns for the manufacture of cement were originally devised at least 15 years ago, and have been in use more or less successfully since that time, yet it is only within the last few years that a satisfactory system has been worked out in detail. This process is distinguished by the mechanical and continuous handling of the materials from the crushers of raw material to the stock-boxes containing finished cement, by the success with which powdered coal (the only practicable fuel in this country) has been applied for heating the kiln, and by the complete solution of the difficulties encountered in preparing a refractory lining. In addition the process manufactures an artificially-matured cement, and thus dispenses with the cumbersome process of aeration by turning over and storage.

The Paper is accompanied by drawings from which the Figures in the text have been prepared.