

HISTORICAL CONTEXT FOR QUICKLIME AND CEMENT PRODUCTION

Extracting, Crushing and Transport of Raw Materials

Following sections will deal with the more obvious and interesting feature of a lime or cement yard—the kiln, typically with its dramatic presence and shape—but it is important to recognize several other key aspects of a typical processing operation: the extraction of the limestone, the crushing of the stone in anticipation of firing in the kiln, and the movement of stone (and other added ingredients) to the kiln. A final post-kiln process, involving the grinding of the resulting material to produce the fine powder that would make up either the quicklime or cement ready for use or sale, is featured further on.

Extraction

Getting at the limestone appropriate for quicklime or cement production (there was a composition that manufacturers gradually preferred, as nearly pure and high in calcium content as possible) could be reasonably easy – with great swaths of this sedimentary rock found all over the earth. Where it was easily accessible, and close to the surface, the process was simply a matter of removing what is called the overburden (the soil and vegetation laying over top of the limestone) and breaking it out of the ground. Such operations were very much like typical stone quarries, and in fact many kiln operations were connected to a quarry, with the debris from the quarrying operation, and from less valuable parts of the site used for quicklime or cement production. Even in the nineteenth century, and especially for smaller operations, this work was done by hand, with picks, sledgehammers and shovels. As the industry evolved, and as operations became larger and more sophisticated, large machinery displaced the labourers and their tools.

Some highly sought-after limestone deposits (with perfect compositions or those that contained natural cement) might be less accessible, and so it was necessary to use well-known mining techniques to remove that material. The kind of mining that typified limestone extraction was known as tunnel mining (versus shaft mining). Tunnel mining involved digging into a situation horizontally and moving material back through the tunnel to the entrance – and then to some other location. Three key issues were of concern – maintaining the structural integrity of the tunnel (or tunnels, a common situation), determining the best method for extraction (simple manual labour, with picks and hammers, or with various drilling and boring machines or even explosives) and the best method for moving the material to the mine entrance (in a tunnel mine called the portal), perhaps by a wheelbarrow in the smallest mines and more often by small-gauge rail tracks with loading carts, sometimes in large operations pulled by small “pit ponies.”

Below: During the first half of the nineteenth century, mechanical crushing was not cheaply available. Stone was crushed exclusively by hand, using the cheapest available labour, such as convicts and workhouse inmates. This image shows women breaking up limestone for the bottle kilns (soon to be discussed) in the right middle ground. (Wikimedia Commons)





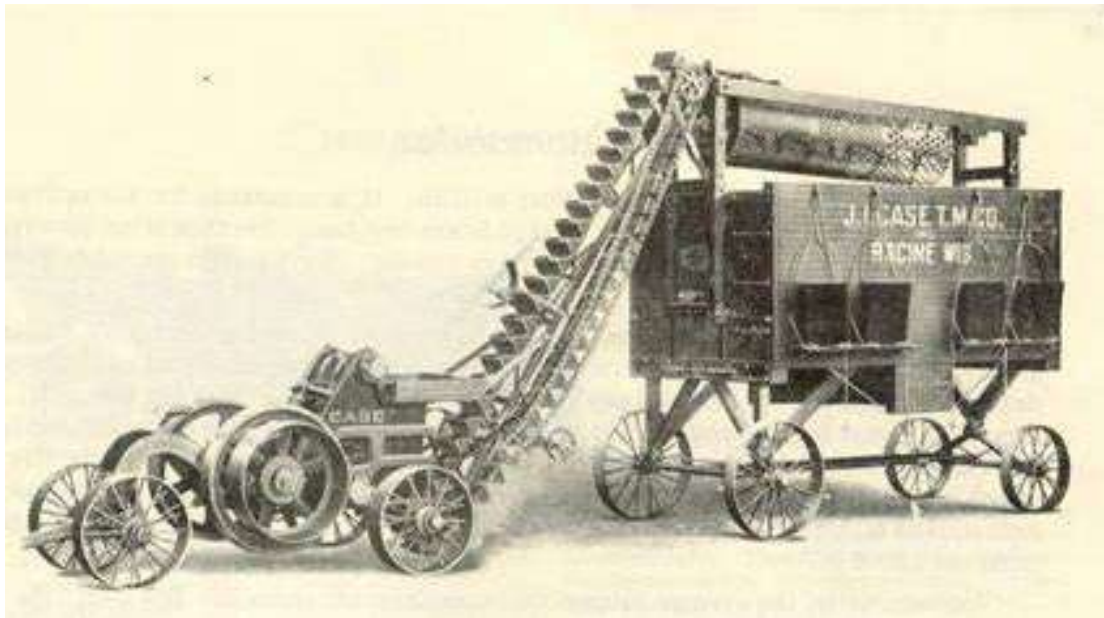
Above left: an example of a stripping steam shovel, seen here in 1920 – used to scoop up large amounts of broken-up limestone at one go. (The State Historical Society of Missouri-Kansas City)

Below left and right: Opening to a tunnel mine, with rail tracks and then interior of a mine with a pit pony hauling ore wagons. (Both images ca. 1890 and courtesy Wikimedia Commons)



Crushing

Invariably the chunks of stone removed in the first step of processing were too large for placement in the kiln. As will be seen, it was essential for effective kiln operation for the limestone to be broken down to about the size of a golf ball – a piece 2 ½ inches around was the maximum for a good burn. It was thus essential that any quicklime or cement yard have at least one crusher on site; for larger, industrially-scaled operations there would invariably be more, and of course of a larger capacity. By the late nineteenth century, the mining industry was well enough along in its technological developments that it was a simple matter for large cement factories to secure that machinery for their uses. The kind of crusher used on almost all limestone operations was called a jaw crusher. This device had its origin with the “Blake Crusher,” an 1858 design of American inventor Eli Whitney Blake. The device was simple in its concept – cast iron (later steel) opposing jaws moved in a reciprocal motion, but only a few millimetres at a time, ensuring that material was cracked at the “in” stroke, allowed to fall further into the crusher with the “out” stroke, and then further crushed again with the next “in” stroke. This kind of simple technology had a number of variations over the years, with slightly different jaw motions, but the Blake design remains in common use today.



Advertisement for a rock crusher from the Case Co. The promotional text for the machine noted here read: “Case crusher Size B has a jaw opening 20 inches long, and about 10 inches wide. The machine is mounted on wheels, making it convenient to move from place to place. The crusher is provided with an elevator for elevating the crushed stone, which is adapted for use with our portable stone screen. The weight of this size crusher is approximately 7 ½ tons; its capacity 15 to 25 tons per hour.” Note the actual crusher, likely a version of a Blake crusher, is seen at the left of the image, emblazoned with the word CASE. The “elevator” rises from this apparatus to lift crushed stone to the upper stone screen, from whence it is dropped into the wagon. (Wikimedia Commons)

Production of Quicklime

As noted above, it is mortar that acts like a paste to hold the more obvious building materials—the bricks or the stones—in place. Once it sets, or hardens, mortar binds the building blocks to fill and seal irregular gaps between them, and helps to spread the weight of the materials evenly throughout a wall. Mortar has been used for centuries, with earliest examples dating to the 10th millennia BC and the buildings of the City of Jericho. The earliest mortars were simply mud mixed with clay or sand and water, and were thus easily eroded. It was not until the discovery of quicklime (often just called lime) that lime-based mortars gained their enduring importance in masonry construction. Quicklime was the result of heating small chunks of limestone, which burned off that material's carbon dioxide, leaving a slightly caustic residue. When this material was ground up and mixed with sand and water, the result was a paste that quickly hardened, forming a solid and fairly durable bonding agent. Lime mortar was certainly used in Ancient Egypt, and all civilizations thereafter, through the Middle Ages, into the Victorian period, and of course into Manitoba in the early nineteenth century.

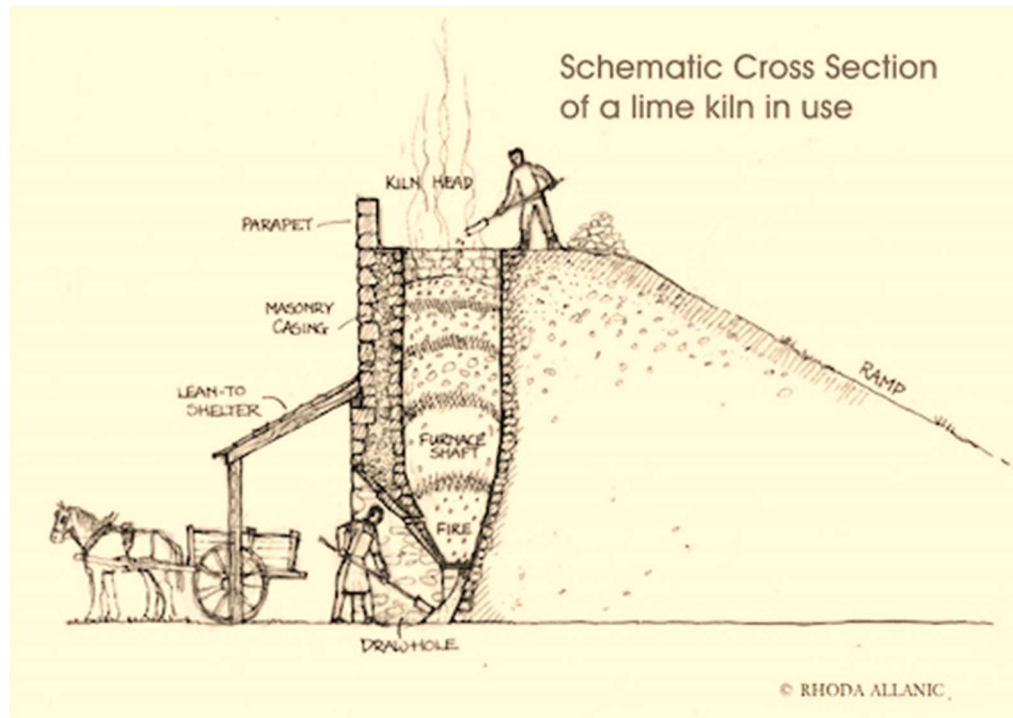
The actual production of quicklime evolved over time, from the simple burning of broken limestone in a pit to more sophisticated kiln technologies in the eighteenth and nineteenth centuries. No matter the size of the kilns, the process was quite straightforward. Layers of broken or crushed limestone were alternated with layers of combustible materials – in early times wood, and in later centuries coal; where coal was not available wood continued to be used well into the twentieth century. It is interesting to note that these structures were not the kind we commonly associate with kiln processes, in which materials like ceramics or bricks were placed in the chamber and then heated so that their materials fused and bonded; lime kilns were completely filled with material that was heated to drive off a constituent, with the resulting material retrieved once sufficiently cooled.

The common feature of smaller lime kilns (which came to be called pot kilns) was a cup-shaped burning chamber, with an air inlet at the base called the "eye," constructed of brick. Limestone was crushed often by hand, with hammers, to fairly uniform lumps (about 1–2½ inches). Successive dome-shaped layers of limestone and wood or coal were built up in the kiln on grate-bars placed in a grid across the eye. When loading was complete, the kiln was kindled at the bottom, and the fire gradually spread upwards through the materials, in totality known as the "charge." When burnt through, the lime was cooled and raked out through the base. Fine ash and other debris (called "riddlings") were fairly easily separated from the burnt stone. Only lump-sized limestone could be used in the process, because the charge needed to "breathe" during firing, ensuring a complete burn of all materials in the kiln – chunks that were too small burned completely and chunks that were too large left interior contents unburned. This aspect of the technology—the size of material—also limited the capacity of kilns and explains why kilns were all generally the same size, about eight to ten feet in diameter. Above a certain diameter, the half-burned charge would be likely to collapse under its own weight, extinguishing the fire, mixing up all the contents and thus ruining all the hard work.



This photograph of an old English pot kiln shows the typical situation for such operations – set into a hillside, to allow easier access at both key levels of the structure – at the top, where limestone chunks and wood or coal would be deposited, and at the bottom where the residue would be removed. This or smaller versions like this would have been found in many areas of Manitoba. (Wikimedia Commons)

A kiln usually took a day to load, three days to fire, two days to cool and a day to unload, resulting in a one-week turnaround time for each burn. The most sophisticated kilns typically produced 25 to 30 tons of lime in a batch. The degree of burning was controlled by trial and error from batch to batch by varying the amount of fuel used. Because it was difficult to control the levels of heat in the kiln, there were large temperature differences between the centre of the charge and the material close to the wall – this meant that there was considerable waste in the process, with a mixture of under-burned, dead-burned (the term for over burned stone) and lime that was deemed acceptable, and defined as well-burned. Typical fuel efficiency in the process was low, with half a ton of coal being used per ton of finished lime. Where masonry construction was common, in larger urban centres, quicklime production was carried out on an industrial scale, with sites that might have up to seven linked kilns combined to produce many tons of quicklime at a time.



A traditional lime kiln – set into an embankment; this example is actually deeper than a typical kiln, which might be just eight feet high. Note the masonry wall surfaces at the front of the cavity and the domed layers of materials in the cavity – the darker features represent the wood or coal layers. Also note the angled brick feature at the base of the structure and the eye and grill at the base, where the burned limestone was extracted. (Wikimedia Commons)

This industrial-scaled lime kiln at Froghall, in Staffordshire, England (at right), with its fine stone and brick facing walls (12 feet high and 150 feet long), nevertheless still employed the traditional technology of a simple pot kiln seen above. This structure was set into a hillside behind, and material was brought to the top of the kilns via horse and wagon and dumped into the individual kilns. Dome-layered contents would be fired as per the prevailing technology, and material removed from the low round-arched openings at the base. Note that the kilns were adjacent to a waterway, which ensured easy transport on barges to retail operations or worksites. The first kiln at Froghall was built in 1786, with four more added in 1808 and another two at a later date. The operation was closed in 1920. This area of Staffordshire is well known for its limestone deposits, and even now 18 historic lime kiln sites are still extant.



Froghall Lime Kilns, in Staffordshire, England. (Froghall Historic Site)



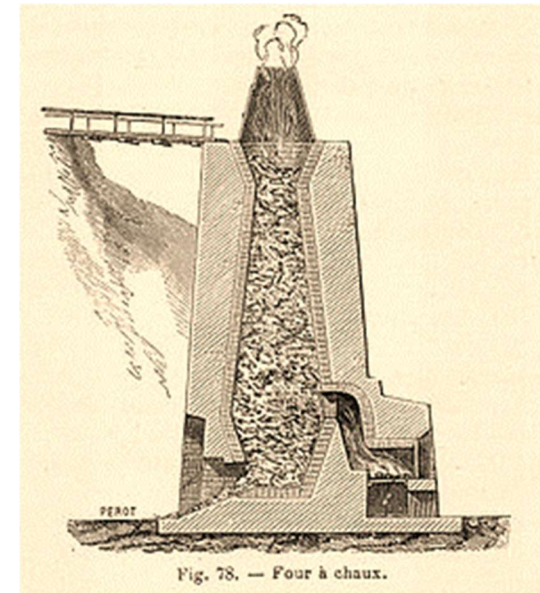
At left: Historic photographs (Froghall Historic Site) show the Froghall operation during a burning, ca. 1890. Note of course the clouds of smoke emanating from the kilns and the enormous quantity of limestone debris covering the hill slopes and piled in railcars. We presume the loose stone in the cars had yet to make its way to the kilns, whose access road was further down the tracks and then to the left. It is not clear why there was so much broken stone on the hillside – perhaps a limestone quarry was further up the slope and this was one way to get the materials to the rail lines. Also note in the middle foreground and to the right the rail cars filled with finer material – this is presumably the quicklime residue ready to be taken to a crusher somewhere else on site. Also note in the top photograph the roofed features that protected the lower-level opening of each kiln, allowing for removal of material even in the rain.

The historical overlap between the traditional lime kiln and those technologies that embraced new cement-making approaches (see next section) in the 1870s and 1880s in Europe, and later in North America, mean that it is sometimes difficult to determine whether a kiln produced quicklime or cement, or both. This is because the essential loading and firing processes were basically the same – putting chunks of limestone (and for cement, other materials) into a kiln with alternating layers of either wood or coal, ensuring a consistent combustion of all the contents. And so old kiln types, as well as new kiln developments, came to straddle that moment in history when both materials were being produced. For the most part, these new kiln types will be covered in the next section, "Production of Cement," but one interesting kiln type that likely was used for quicklime production is noted here – the shaft kiln.

The cross-section illustration (right) shows a fairly sophisticated shaft kiln from France (ca. 1860). This design has elements of the traditional quicklime pot kiln, in particular at its base, where slanted wall features ensured that material was directed to fall close to the opening (on the left-hand side) where it could easily be removed by rake. The fire source was also at the base (on the right-hand side), but here separated and with its own opening into the main chamber. The obvious major difference was the chamber itself, which was quite tall, and doubly angled, with a wider opening at the top pinched to a narrowed shaft diameter a few feet below. As will be seen in the next section on cement manufacturing, it was this kind of detail (and the location of the fire source) that would engage kiln designers for many years – that is, in the control of heat inside the kiln. It is also notable here that the structure was freestanding, and not built into a hillside, as was common with older pot kilns. This development likely was based on the ability to get raw materials to the top of kiln by mechanical means, and also presumably on the likelihood that the raw materials might be brought to site from a more distant source – likely by rail.

The illustration shows a gangway leading to the top of the kiln, and presumably the main limestone source was adjacent. Most shaft kilns were about eight to 12 feet in diameter (if circular, and about 12 to 15 feet wide if built on a square plan) and 40 to 50 feet high, and could be surmounted with an additional stack for natural draught (as suggested in this French example). Finally, and perhaps most importantly, the illustration reveals a key aspect of all of this thinking (loading, firing, retrieval) – the unlayered display of raw material in the kiln. Where older quicklime kilns required an alternating layering of limestone and wood or coal to ensure a good burn and the production of an acceptable product, these new kilns could achieve a similar result with a more haphazard loading, although it was still necessary to fill the kiln with equal amounts of stone (and for cement production various types of clay) and combustible materials. Another major benefit of the shaft kiln was that it could be continuously loaded, with materials added at the top of the shaft, and with the residue continually withdrawn at the bottom, and then typically removed to a nearby crusher. While this approach, and this kiln design when used for the production of quicklime, allowed for nearly continuous operation, as the charge within could be topped up over and over, and thus of greatly improved output, the result was often a more variable product – with much of the clinker over-burned. As will be seen in the next section, this

unscientific approach—of the measurement of materials and temperature control—would be a major source of concern in the design of cement kilns.



French Shaft Kiln, ca. 1860. (Wikimedia Commons)



Views of two old Canadian lime kilns: above a sketch of the ca. 1870 Rockwood, Ontario operation, seen in 1923 (W. Godfrey, Toronto Public Library); and near left, the ca. 1880 Howard operation in Kingston, Ontario (Wikimedia Commons). These two images show a slightly tapered shaft form.



Production of Cement

As noted above, the knowledge of the production and use of quicklime has been known for many millennia. And while similar knowledge of cement does not have quite the same lengthy pedigree, the Greeks and Romans were aware of the properties of cement more than 2,500 years ago. Both ancient cultures experimented over several hundred years (500BC-450AD) with the traditional mortar mix of burnt and ground limestone, combined with sand and water, adding broken potsherds, powdered brick or volcanic ash, amongst other substances, to improve the workability and durability of the final product. The Greeks added volcanic tuff from the island of Thera to their traditional quicklime mix, while the Romans used crushed volcanic ash. The Roman writer Marcus Vitruvius Pollio in his treatise *De Architectura* of the 1st Century BC advised that there was "a kind of powder which from natural causes produces astonishing results. It is found in the neighborhood of Baiiae and in the country belonging to the towns round about Mount Vesuvius. This substance when mixed with lime and rubble not only lends strength to buildings of other kinds, but even when piers of it are constructed in the sea, they set hard under water." The Romans would go on to use this material—what we now understand to be cement, and the resulting mix to be concrete—for buildings and structures that have endured to the present day – the Pantheon, Baths of Caracalla and the system of aqueducts that still stand in many parts of the old Roman world. The Romans called their cement *pozzolana*, which we now know was distinguished by the presence of aluminosilicate minerals, and was so named because it came from a town called Pozzuoli, west of Naples.

The historical record suggests that the Roman knowledge of cement and concrete was mostly lost during the Middle Ages, although there were occasional examples of its use as a filler. But for the most part, the strict discipline of Roman practice was lost, and the great Gothic cathedrals that have come to define that period were built with stone and the most typical mortar – composed of sand, water and quicklime. It was not until the mid-eighteenth century that cement made a comeback.*

There are thought to be a few explanations for this development: one was the quest to discover a material that could stand up to water – in canals especially but also for docks, bridges and many other structures that were near or in water, and which were becoming increasingly important for growing industrial economies; another was the interest in creating wall surfaces on new buildings that had the

* A great deal of the following information has been drawn from a website developed by Dylan Moore. Mr. Moore's site, *Cement Plants and Kilns in Britain and Ireland*, (web: www.cementkilns.co.uk;) is a major source for information on all aspects of cement production, both historical and contemporary. The site has an important focus on kilns, with expert commentaries, numerous technical observations and useful photographs and drawings. Another reference, noted on Mr. Moore's site, and valuable for many following details is *Calcareous Cements* by Gilbert Richard Redgrave & Charles Spackman (C. Griffin & Co., 1922).



Interior view of the Pantheon in Rome, dedicated 126 AD. (Wikimedia Commons)

appearance of ashlar-cut stone, but at a much lower cost (this material ultimately turned out to be stucco); another was simply the age in which all of this activity was percolating—the so-called Age of Reason. through the eighteenth century—in which a more scientific approach was brought to bear on all kinds of issues.

The first reported cement experiments were undertaken by John Smeaton, an English civil engineer who was developing a structural plan for a new lighthouse at Eddystone on the English Channel, which went up between 1756 and 1759. Smeaton needed a mortar that would set up in a short period of time, between high tides, and retain its strength. His experiments focused on different limestones, quicklimes and additives, noting in his research that the "hydraulicity" of the quicklime was directly related to the clay content of the limestone used in its production.

While Smeaton's observations—that a mixture of limestone and clay, when heated and mixed with the traditional mortar mix appeared to give the resulting paste greater strength and durability—had little practical effect for other construction projects of the day, a product called "Roman Cement" gained popularity in England in the 1780s. Developed by James Parker, this material was created through the kiln-heating of a material called *septaria* (nodules found in London-area clay deposits that also contained chalk) that was ground into a fine powder and added to the traditional mortar mix. The success of Parker's Roman Cement (which was not in the least like ancient Roman pozzolana cement, but was acknowledged as "natural," that is not the result of experimental mixing of ingredients) inspired other manufacturers to develop their own patented artificial mixes, using various proportions of kiln-fired limestone or chalk and clay.

We are finally to the short period when Portland cement as we know it was developed. The story begins with the man who gave it the name now used in most countries: Joseph Aspdin, who observed in an 1824 patent application for his cement mix that the material had the same colour as a well-known and highly-prized stone quarried near Portland, England. But there were other developers, in Britain and elsewhere in Europe, who were working on this issue – given how its refinement would not only bring scientific recognition, but might also bring financial windfalls as well, if adopted by the construction industry. It should be noted that around the same time as Aspdin was promoting his new Portland cement, that in United States there was great activity on this front, beginning with the discovery of natural cement deposits in New York in 1818 and used in various civil engineering projects, particularly canals, by the 1820s.

It is now understood that Joseph Aspdin's product was not a "true" Portland cement, and it was his son, William Aspdin, who in 1842 re-patented his father's proprietary mix, and thus created the first real Portland cement. Dylan Moore settles on William Aspdin's operation at Rotherhithe from 1842 as the first productive Portland cement operation in the world, and notes the primary ingredients used there as chalk and clay.



William Aspdin, 1815-1864, the Englishman credited with the inaugural production of "true" Portland cement in 1842. (Wikimedia Commons)

While Portland cement ultimately eclipsed all other cement competitors, it was not immediately the dominant choice in the construction industry. It is notable for this current project that Portland cement was only introduced to the North American market in 1868, and that local production of Portland cement only attained a large scale in the 1880s, in Pennsylvania. For decades, in fact, it was the natural cement mainly mined and processed in New York state (noted above) that was the preferred additive option for concrete in the United States until the early 1900s. But eventually the benefits of Portland cement, and of the concretes that resulted, compared with natural cement, were too persuasive: it was stronger and took a shorter time to harden, both obviously great advantages in the construction industry; and if those considerations were not convincing enough, it was determined also to be more cost-effective to produce. As for the cement-production industry, its evolution over just 40 years, from William Aspdin's first operation in 1842, to new kiln technologies developed in 1877, was astounding. The following short overview addresses the key processes, technologies and machinery, with an important caveat being that this evolution was so marked with remarkable developments in processes and machinery that only some of the highlights can be featured here.

Mixing

The first point to note concerns the ingredients of Portland cement, which are primarily limestone or chalk (about two thirds of the mix) and clay (about a third of the mix), along with minor, but of course consequential, additions of iron in various forms. The first cement production operations typically were strategically situated near at least one of these two key ingredients – a bed of the limestone best suited for cement (in England chalk was often the preferred primary ingredient), or for a likely source of clay. Whichever key material was not immediately available was brought to the site, hopefully at not too great a cost. Other materials, including the fuel for the operation (typically by this stage of industrial activity that would have been coal), would also have been brought in, likely via rail.

In the initial stages of Portland cement production, it was imperative that manufacturers ensured that all of these raw ingredients were mixed appropriately, and at the right percentages. It was thus necessary to weigh and measure the various materials, and staff and machinery were now needed at this initial point of production. Considerable attention was also brought to bear on the best ways to prepare the limestone-clay mix. Two procedures quickly became the dominant options, usually dependent on the nature of the raw materials – the “wet” method and the “dry” method. Both brought a whole new level of sophistication, and equipment invention, to the practice.

The wet process involved the mixing of ingredients—what was coming to be called the “rawmix”—in a liquid slurry, with various percentages of water. The wet method was typical for operations that were focused on chalk, rather than limestone, and was common in the United Kingdom, where we have seen a great deal of the cement-production invention going on. This was understandable – chalk is a “wet” material, and the heat resources to dry it made it economically unfeasible in a dry process.

We look to Dylan Moore, with tenses only changed, for this useful introduction to washmill technology: “The washmill can be thought of as a giant kitchen liquidizer. Although washmills escalated in size during their history, the basic design became standardized quite early. The mill consisted of a circular (or often octagonal) stone-lined bowl with a rigid centre-post, about which rotated a set of radial arms from which harrows were suspended on chains. The harrows each contained 10-20 vertical steel-bar teeth or “tines.” The rotation of the radial arms dragged the harrows around the mill and they agitated the coarse raw materials, with water constantly added to the mill.



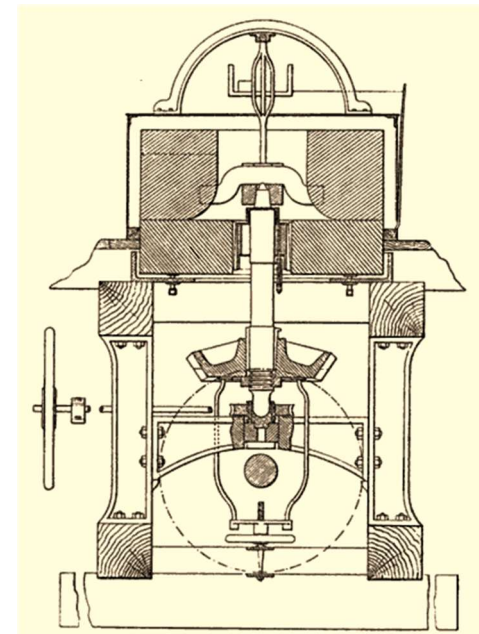
Cement plants that employed the “wet” method of mixing ground limestone and clay typically relied on so-called washmills for the process. This example, from the English operation at Wilmington, was 66 feet across. (Dylan Moore)

The action of the mill was to a large degree autogenous – that is, the motion of the larger chunks of raw material crushed the smaller pieces.” Mr. Moore notes elsewhere that this process was identical in every respect with that used in the ceramics industry for centuries to produce fine-grained pottery clay. Another on-line source notes that “typically two or three washmills were connected in a series. Relatively hard minerals in the mix (such as flint, a common constituent of chalk) were more or less untouched by the grinding process, and settled out in the base of the mill, from where they were periodically dug out.”

In terms of cement-factory design, the step following the wet-mixing stage led to the development of large “slurry backs” and “drying floors” that were used to prepare the material for next steps in the process. Where the slurry, or “slip” was particularly thin, with about 80% water, it was placed in slurry backs where it was allowed to settle. These slurry backs were large tanks or reservoirs, often several thousand square feet in area, and three to six feet deep. This set-up had the dual effect of allowing larger particles to drop to the bottom, and permitting water to be decanted from the top. Early practice involved settling for as long as six months, after which a stiff cake was formed which could be cut into blocks and made ready for other steps in the process. Not surprisingly, the exceedingly long set-up time was deemed a major drawback, and a new step in the process was added. This involved the addition of drying floors or “flats,” large horizontal structures on which the mix was placed and heated underneath so as to draw off up to 25% of the water content. The development in 1870 of the “thick slurry” process, predicated on the reduction of the water content, allowed some operations to speed up their processing time—to just a few days—but at a greater cost for fuel in the heating stage.

Crushing

Where limestone was the predominant raw material in cement production, and thus where the dry process typically was used, it was essential that the stone be broken down into granular form for further processing. This part of the operation invariably involved two discrete steps, and two distinctly different pieces of equipment – crushers and grinders (grinders were additionally used for coal grinding and at the final stage of cement production, as will be seen). Crushers have already been introduced earlier, in the section “Extraction and Crushing,” with reference to the Whitney crusher, but it is important to note that as the Portland cement industry grew and matured in the latter half of the twentieth century new options for large and improved crushing machinery were developed and used – especially impact crushers and gyratory crushers. But the more significant piece of equipment was the grinder (often called a mill) that was essential for the fine-grinding needed in large cement operations. There were scores of individual designs, but only five general types of grinding mills: flat stones, roller mills, tumbling (or ball) mills and tube mills. We focus only on two here, that are actually the simplest in form and operation: the flat stone mill and the ball mill, with descriptions from Dylan



*Section drawing of a flat-stone crushing mill.
(Dylan Moore)*

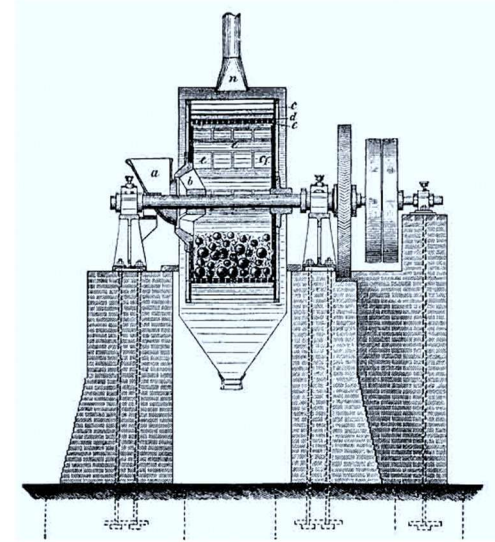
Moore (with tenses changed). It is notable that this grinding stage was even required in wet process operations, where it was still necessary to reduce the large particles left in the bottom of washmills after that process had been completed.

“Flat stones were used in the Portland cement industry from the outset. The technical drawing above, from David B. Butler, *Portland Cement: Its Manufacture, Testing and Use*, E. & F. N. Spon, Ltd: 1899, shows the two large stones at the top of the apparatus and a turning shaft beneath. The industry inherited these kinds of machines as a completely mature technology and continued using "standard" equipment, operated by craftsman millers recruited from the flour industry. This accounts for the almost complete lack of any innovation during the half-century in which the industry used them. The standard mill had a diameter of 54 inches, and the hundreds of mills installed rarely varied from these dimensions. Mills would usually be arranged in sets of four or five, driven from a common shaft. The mill shown has a rotating upper stone 20" thick, with a 20" diameter feed hole ("eye"). The stones were made from a hard rock, and white "French burr" was almost variably used, because its low wear-rate more than compensated for the high cost of the stone.”

“The tumbling or ball grinding apparatus on a cement yard borrowed their technology from the ceramics and pigment industries, and their refinement of the tumbling or ball mill. These kinds of mills consisted of iron drums filled to about a third of capacity with flint beach pebbles, and lined with ceramic or squared flint blocks (the example at right, shown in a patent drawing, was from the German company Krupp Grusonwerk). Flint pebbles had the advantage that they were naturally smooth and rounded, but had the hardness of quartz, and so could be used for grinding most minerals. The chunked limestone was added in quantity sufficient to fill the voids between the pebbles, often with added water, and then rotated, often for many hours or days. Once done, the whole contents were emptied out, and the pebbles were separated with a sieve. For the cement industry, there was a need for continuous grinding processes, to put unground materials into the mill continuously, and to withdraw ground product at the same time. Because the mill was to run non-stop, the structure and grinding elements had to be strong and wear-resistant.”

Kilns

Whether wet or dry, the final presentation of materials was all directed to the key feature on any cement-production facility – the kiln. It was in the kiln that the various materials were ultimately transformed into “clinker” the technical term used for the output, that once mixed with a few other minor ingredients (like gypsum), and then ground to a powder, became Portland cement. It was the kiln that quickly became the key focus for much of the creative energy brought to bear on the numerous improvements in the industry over the course of the latter half of the nineteenth century. The most common designs are featured here—bottle, chamber, shaft and rotary—but it should be noted that scores of other concepts, in England and elsewhere in Europe, were also vying for acceptance, and that variations on each of these four major forms were abundant.



Section drawing of a ball grinding mill. (Dylan Moore)

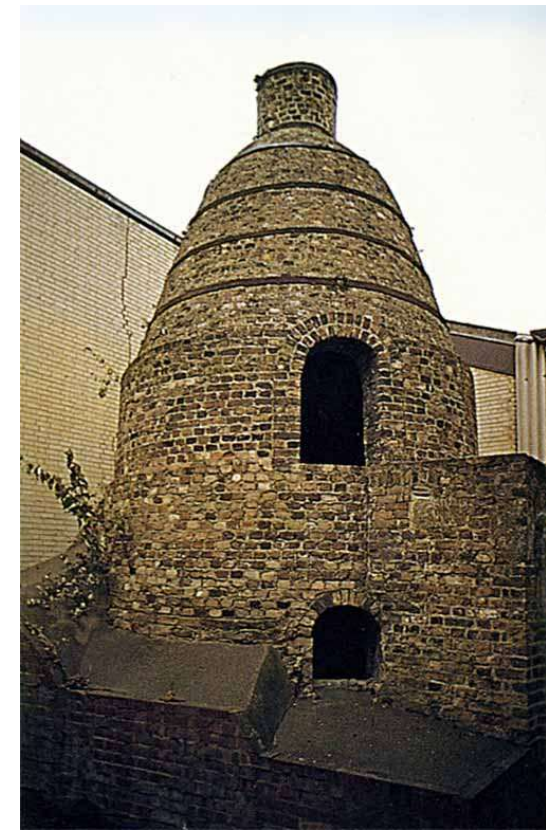
There were two essential functions of a cement kiln. The first was to drive off via extremely high heat (at least 1450°C) various elements in the form of gases – this was essentially carbon dioxide, removed from the limestone. This heating in a cement operation was called “calcination.” The second function was to unite or fuse in a chemical process the remaining materials into a new substance - clinker. Clinker came out of the kiln as red-hot balls, about the size of marbles. It has been understood from the earliest times in the development of the Portland-cement industry that in order to make the most of the kiln, the mix had to be very finely ground or mixed, it had to be thoroughly homogenized as a mixture and the composition had to be tightly controlled. Another common issue that attended kiln operations was the fuel composition and delivery mechanisms. The early generations of kilns typically employed coal or coke (a byproduct of coal that burns without smoke), which was simply supplied in lump form, without refinement, and set up in kilns in the traditional layers seen with quicklime kilns.

Bottle Kilns

The first foray into new cement kiln technologies (from the late 1860s and active well into the 1890s) focused on a type familiar in the ceramics industry: a light brick structure built upward from the lime-kiln hearth at the base, either in conical form or in bottle-top. This kiln came to be called a bottle kiln, and combined the form of the ceramic kiln with the loading practices familiar in quicklime production. The rawmix (combinations of crushed limestone or chalk, clay and other minor ingredients) was heaped into the kiln in domed layers, alternating with wood or coal, ensuring that the charge kept its shape throughout the burning process; failure and collapse of the charge would ruin the batch. As noted with lime kilns, this weakness limited the diameter that could be spanned. Bottle kilns were typically 10 to 18 feet in diameter, with a depth somewhat greater than the diameter. The key goal of this kiln design was thus not to increase production, but to form a chimney of sufficient height to considerably increase the natural draught produced within, and thus control the heat and ensure more consistent burning – and thus attain more productive results.

The construction of the bottle kiln was straightforward. The base and the conical section were built from ordinary bricks and mortar. Iron hoops around the outside of both the base and the cone provided tensile strength and allowed thinner brickwork. The lining of the kiln was made with “fire-brick” – the common siliceous refractory product of the early industrial period. The fire-brick lining was smoothed out with a carefully controlled curvature by building against standard wooden forms. A doorway was made in the upper cone section to allow the rawmix to be put in. At the base (the “eye,” seen above in lime kilns) a grate of wrought iron bars was set in place, and an access tunnel led from this to the outside. The air supply for the kiln passed through this tunnel. A small access door between the tunnel and the kiln immediately above the grate was used to extract the finished clinker. All the side doors were bricked up during burning, and plants maintained a team of bricklayers for this and for repairs to the kilns’ fire-brick linings. As a rule of thumb, a ten-foot kiln would produce around 10 tons of clinker per charge, and an eighteen-foot kiln would produce 30 tons. The typical production cycle for a bottle kiln consisted of loading, burning, cooling off and emptying. It should be noted that both wet and dry processes for material preparation were both commonly used on bottle kiln operations. Loading and emptying were each accomplished in a 12-hour day shift. Loading could take a day, and

burning could vary from two to four days. Cooling off might take two days. This meant that kilns could be turned around in four to seven days – this latter value a concern for larger operations, which invariably led to new kiln design considerations, like the shaft kiln (below).



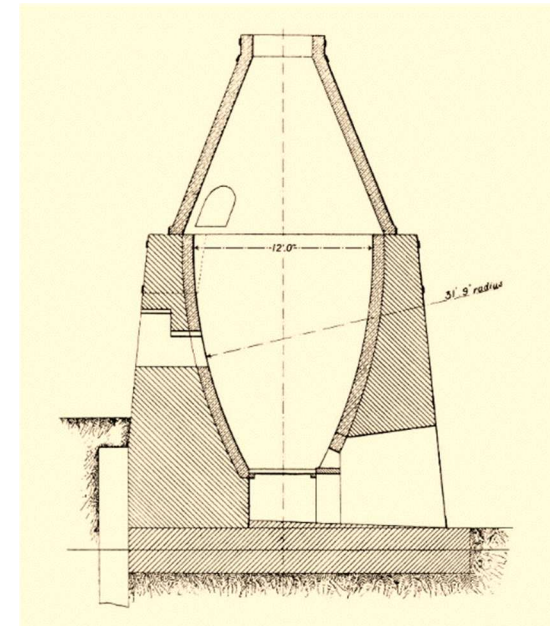
A preserved bottle kiln at Robins, Gravestone, Kent in England, showing the tell-tale form and the various openings that allowed access for rawmix, and also the enclosed upper chamber that allowed for better control of heat in the kiln. (Dylan Moore)



A drawing by David Maxwell from 1926 shows the remarkable bottle kiln collection at the Northfleet, Kent cement plant. Established in the late 1860s, the plant was closed in 1910. (Dylan Moore)

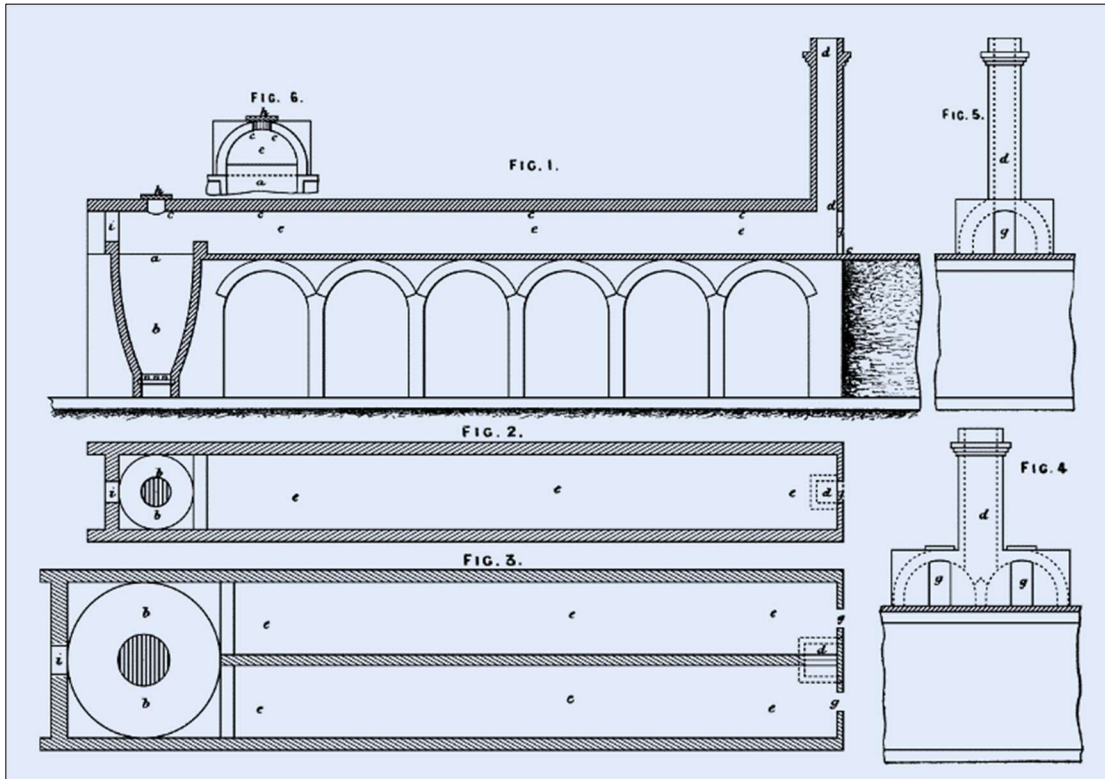
Chamber Kilns

As noted above in the discussion of wet-process production, an obvious problem with that approach was the inordinate amount of space that had to be set aside for this stage of the process, with an additional concern being a major setback in overall production while waiting for the cakes to form up. A major innovation brought the kilns and the slurry backs and drying beds together, and led in to a new cement-plant design that was perfected during the late 1860s and early 1870s. The kilns themselves were called chamber kilns, and combined the traditional cup-shaped form of a lime kiln (still requiring layered and domed loading of rawmix and fuel) at one end of the design with an attached long slurry bed that stretched many feet in a linear progression. The new chamber-kiln set-up allowed for the construction of much more compact plants with a low capital cost, and chamber kiln operations, typically with several attached kiln-and-bed structures, became the standard format for new ventures. By 1889, chamber kiln capacity exceeded that of bottle kilns. A plant at Arlesey in the United Kingdom was featured in *The Engineer* magazine in October of 1886, with the article noting that the available “six kilns allowed one kiln to be turned around every day, Monday to Saturday [and] each working day a kiln would be emptied of 20 tons or so of clinker.”



A cross-section illustration of a bottle kiln shows the enduring egg-cup shape seen in earlier quicklime kilns, and the situation at the base – where the fire was created, and where finished product ultimately would be removed. Also note the intermediate openings that allowed access for rawmix, and the enclosed upper chamber that allowed for better control of heat in the kiln. (Dylan Moore)

It was common for large operations that had invested in the bottle-kiln technology to simply remove the topmost “chimney” features, and to convert those older kilns into chamber kiln structures. It is also worth noting here that while many English plants were focusing their energies on the more profitable creation of cement, many still set aside areas of their operations for the simpler, but still valuable, production of quicklime. This is perhaps obvious, especially where a plant could use its readily available limestone for the manufacture of both products.

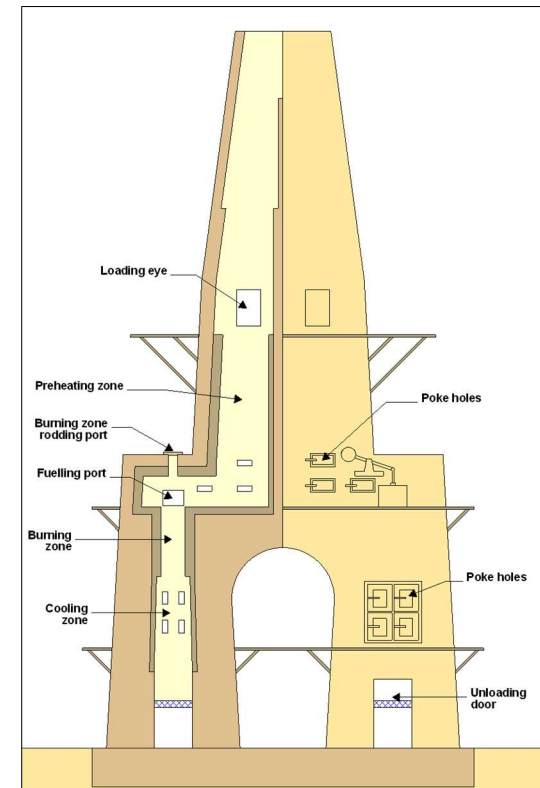


Mr. Johnson's patent drawing showing one version of his chamber kiln design from 1870. The longitudinal section drawing at top shows the placement of the kiln at the left-hand side and the slurry bed (raised on a brick-arched form) stretching off to the right. A tall chimney, also shown in the right-hand side elevational drawings, ensured good draught and heat movement in the system. The drying chamber, of the same width as the diameter of the kiln, had a specified length of 80 to 100 feet. The floor tilted slightly towards the kiln end, allowing a thicker layer of slurry to form up where the gas temperature was at its highest. (Dylan Moore)

Shaft Kilns

The key attribute of a shaft kiln was its continuous production. Bottle kilns and even chamber kilns were greatly limited in their capacity and production because only a single batch could be burned over a several-day period, with loading and unloading interrupting the process. But a shaft kiln could be topped up continuously, with raw material and wood or coal added as the previous charge was fired and processed, and run on a nearly 24-hour basis. As seen with the development of bottle kilns, a key preoccupation of the designers of cement-producing shaft kilns was with the control of heat – not just to ensure high even temperature that would lead to the best technical results of the clinker, but also in cooling periods in the kiln that were another key part of the process. At its most essential level, shaft kilns acted like chimneys, with the form and height not just for loading more material, but to ensure a constant and effective draught in the kiln, and thus bring a sustained and controllable heat throughout the burning process. There was a great deal of careful observation and thought brought to bear on this issue, and consequent design solutions. Most shaft kilns were about eight to 12 feet in diameter (if circular and about 12 to 15 feet wide if built on a square plan) and 40 to 50 feet high, and could be surmounted with an additional stack for natural draught. A typical shaft kiln produced between 100 and 200 tons per day. Shaft-kiln designers also were very interested in addressing a drawback that tended to affect only the shaft kiln design. This involved the tendency of various materials in the kiln—mostly iron particles—to sinter, that is, to form thick coatings on the interior brickwork which would eventually choke the kiln, rendering it inefficient and in the worst cases even useless. The many shaft designs that emerged during the last half of the nineteenth century were aimed at tackling these various issues. There were many designs for shaft kilns, but the only ones used to any extent in Britain were known as the Dietzsch kiln and the Schneider kiln. In continental Europe, other shaft kiln designs included the Schoefer, Riiser, Hauperschild, Hotop, Stein and Perpignani-Candlot kilns.

It has been difficult to identify most of these other European designs, besides their names, with the exception of some archival images of the Schoefer kiln, common in Denmark (and as will be seen below, also in the United States). And the Schneider kiln, though fairly popular in England in the late nineteenth and early twentieth centuries, is difficult to appreciate from the existing sketchy technical drawings, and a handful of photographs of sites; and none of these are helpful in understanding the distinct processes of this kiln, where all of the design innovations are within. Dylan Moore has this information: “The key innovation of this design [was] the comparatively slender cool air intakes along the sides of the preheating and burning zones [of the kiln], as well as the slight constriction in the shaft diameter just above the cooling zone. These features ensured that sintering blockages were discouraged by taking the pressure off the hot material, by keeping the burning zone lining cool, and by keeping fuel away from the lining. It allowed for nearly continuous operation, as the charge within could be topped up over and over, and thus greatly improved output, the result was often a more variable product – with much of the clinker over-burned. At the same time, production was typically prodigious, with output up to 120-200 tons per week.”



Schematic of a sophisticated Dietzsch kiln. The captions are difficult to make out in this example: at left, top to bottom: Loading eye, Preheating zone, Burning zone, Fuelling port, Burning zone, Cooling zone; and on the right: Poke intakes, Poke holes and Unloading door. (Dylan Moore)



This Dietzsch kiln (from 1885) was a two-tiered operation (upper and lower shafts), with the distinctive form (to modern eyes like a rocket ship) designed with the sintering issue a key concern. The cross-section illustration on the previous page shows the complex internal dynamic; the image here is of a set of Dietzsch kiln at Barewalls, England. A key to understanding the drawing, and the following text taken from the Dylan Moore website, is to note that the shaft areas shown on the left-hand side of the illustration represent only one of the eight that formed the complex internal arrangements; the photograph suggests this – with the bottom level openings defining each shaft position. Note also the use of a railed conveyor with a bucket carriage that was used to lift the rawmix and fuel up to the main loading door. From Mr. Moore, with tenses only changed: “The upper shaft was fed with lump raw material only. Dried and pre-heated material was withdrawn by hand from the base of the upper shaft (the "hearth"), and was dragged into the top of the lower shaft, with layers of coke or coal added. The lower shaft was provided with numerous poke-holes around the hearth and above the top of the burning zone. The constriction in the topmost section of the lower shaft maximized the draught at that point.”



The Schoefer Kiln

An important site in Lehigh County in Pennsylvania, now called the Saylor Park Industrial Museum, was a major player in the early development of Portland cement in the United States, and in its present condition provides a good view of a Schoefer kiln. Originally called the Coplay Cement Company, this nine-kiln operation was inaugurated in 1892 and ran for 12 years, to 1904. While the museum site clearly presents the kilns as the centerpiece of its interpretive displays, it is important to note several major alternations to the structures. First, the capping roof features on four of the kilns are not original (added much more recently as a preservation feature) and in fact all the kiln stacks originally rose at least another 20 feet (to a height of 90 feet) – they were truncated because of their deterioration. And secondly, the kilns were originally set within a very large building, so that the lower levels—where one can now see all of the openings into the stacks—would not have been visible from outside. The image below, of Schoefer kilns at Aalborg in Denmark suggest this situation. (Dylan Moore)

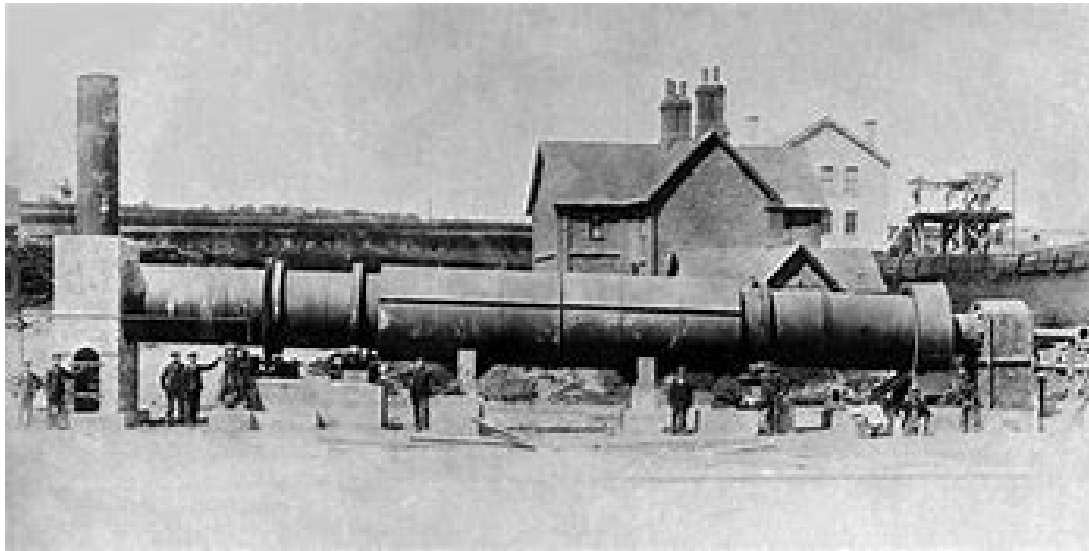


Rotary Kilns

The next (and final) development in the manufacture of Portland cement was the rotary kiln, patented by Frederick Ransome in 1885 in the United Kingdom and 1886 in the United States. The rotary kiln was revolutionary, upending previous kiln technologies, and producing a stronger, more homogeneous mixture and a continuous manufacturing process. It was fairly simple in its concept – in fact it can be observed that the rotary kiln was a shaft kiln turned on its side, at a slight angle to the horizontal, and then loaded and fired as per the shaft-kiln process – with loading of raw materials at one end, firing at the base and along the length of the shaft, and removal at the other end.

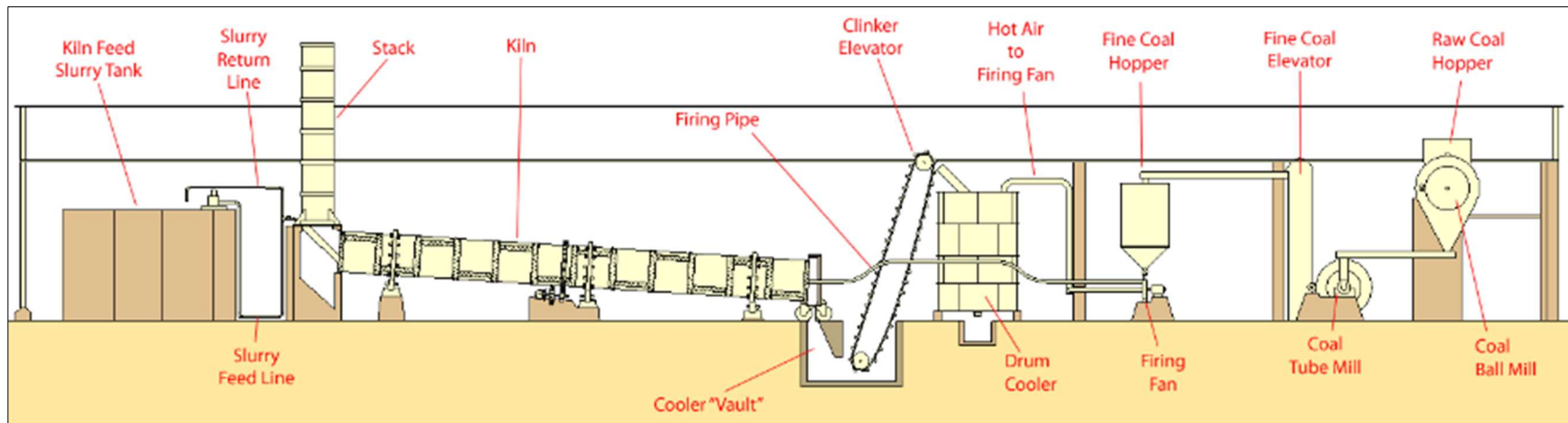
The rotary kiln consisted of a tube made from steel plate, and lined with firebrick. The tube sloped slightly (one to four degrees from the horizontal) and slowly rotated on its axis at between 30 and 250 revolutions per hour. Rawmix was fed in at the upper end, and the rotation of the kiln caused it gradually to move downhill to the other end. At the lower end, fuel, in the form of gas, oil, or pulverized solid fuel, was blown in through the "burner pipe," producing a large flame in the lower part of the kiln tube. As material moved under the flame, it reached its peak temperature, before dropping out of the kiln tube into the cooler. In contrast to bottle and shaft kilns, the material passed quickly through a rotary kiln: it took from three hours to as little as 10 minutes. Rotary kilns could run 24 hours a day, and were typically stopped only for a few days once or twice a year for essential maintenance. The earliest successful rotary kilns made about 20 tons of clinker per day. By 1905, the largest kilns were nearly 10 feet in diameter and almost 200 feet long. At that date, after only 15 years of development, rotary kilns accounted for half of the world's production. Since then, the capacity of rotary kilns has increased steadily, and the largest kilns today (which can be 20 feet in diameter and 1000 feet long) produce around 10,000 tons per day. Rotary kilns brought with them all kinds of innovations and additions – fuel, cooling and so on, too esoteric for our current needs.

Rotary and chamber kilns required one additional component that was not necessary in bottle or shaft kilns – a chimney stack. Because the earlier kiln types were in their form effectively chimneys, their vertical extensions created the draught necessary for more effective burning within the kiln. This was not the case for later kilns, which were not vertically oriented, and which therefore needed the conjoined heating systems and tall chimney stacks for their operation. These stacks, which became larger and taller with ever larger chamber and especially rotary kiln designs, created the draught that continuously moved the super-heated air through the system, and also deposited the debris from burning, as well as the carbon dioxide gas burned off of the limestone, high into the atmosphere. The height of the stacks was primarily designed for improved plant operations, but it also became clear over time that the “polluting” character of the cement plant was somewhat mitigated by having a stack high enough to disperse materials further away from the site, and even hopefully away from nearby residential areas.



Left: This archival image (Wikimedia Commons) shows a typical rotary cement kiln in England. The enormous size is suggested by the men standing about beneath the mighty form.

Below: The Shoreham Kiln System. This technical drawing (from Dylan Moore) shows a Shoreham rotary kiln. The image indicates the general arrangement of the system, suggesting the immense complexity of the whole operation: slurry was fed into a feed tank and return line (on the left-hand side) and then into the rotating kiln itself (a stack at the near end ensured good draught in the tube); finished clinker dropped out into a cooler vault and was moved to a drum cooler via a clinker elevator; a trough under the drum cooler allowed the finished clinker to drop out for collection. The whole firing system was set up to the right of the kiln – with various pipes, hoppers and elevators moving the fuel to the base of the kiln.



Grinding

Even after burning in a kiln, the resulting clinker was not quite in its final necessary form. The ultimate destination for the material was a grinding stage – where relatively small, but usually industrial-sized, machines produced the preferred cement powder (see below right). After grinding, the finished product would be bagged (or barreled) and moved for transport – via horse and wagon in some situations and rail if that opportunity was available; many more sophisticated operations ensured that a rail link was part of the yard planning stage.

A few final observations about Portland cement production bring us up to the present day. The first is that by now there are well-established and highly technical requirements for the definition of Portland cement. From the Portland Cement Association: “Portland cement is produced by heating lime, iron, silica and alumina to extreme temperatures (2,500 to 2,800°F) in a rotating kiln.” Another reference on this site has even more specific definitions of composition: “aluminum oxide, ferric oxide, magnesium oxide, sulfur trioxide, tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminoferrite.” There are eight specific varieties of Portland cement – the most common, and most commonly used in building projects, is known as Type 1. Again, the Portland Cement Association has this direction: “Its highly specified composition must meet these standards for chemical ingredients: 55% tricalcium silicate (C₃S), 19% dicalcium silicate (C₂S), 10% tricalcium aluminate (C₃A), 7% calcium ferroaluminate (C₄AF), 2.8% magnesium oxide (MgO), 2.9% sulfur trioxide (SO₃), and 1.0% free calcium oxide (CaO).” It should be added here that by now the far more common approach to mixing cement ingredients is the dry process, a natural response to the more common sites of cement production – places with preferred limestone sources.

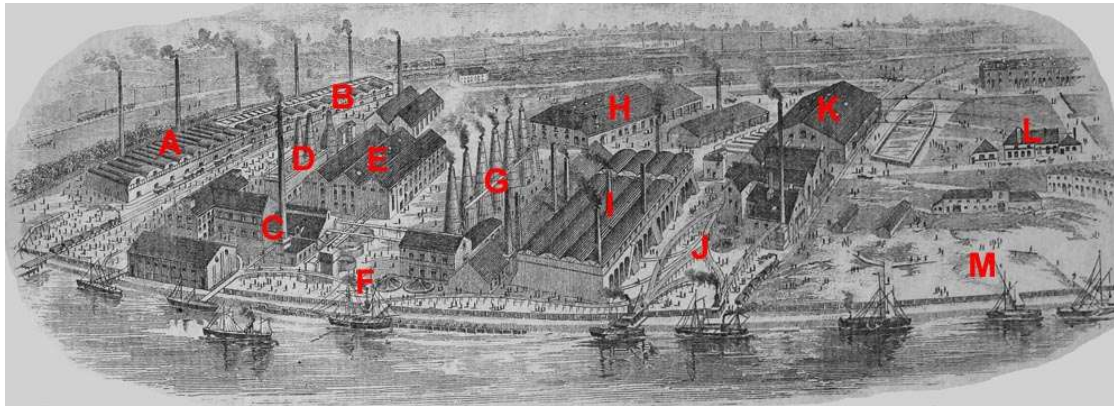
By 2020, 178 years after the first development of “real” Portland cement, and its ultimate use in concrete, that material has revolutionized the built world. It is used more than any other artificial material; more than plastic, steel, glass, brick, cloth or ceramics. As the most popular man-made material on Earth, concrete is the second most “consumed” substance after water. Producing about 10 billion tons of concrete every year, the industry is worth over \$100 billion and employs more than 2 million people in the United States alone. But there is a downside: the cement industry is one of the three primary producers of carbon dioxide, a major greenhouse gas; the other two are the energy production industry and the transportation industry. Two final pages in this section illustrate the enormous size and complexity that attended cement factory development even by the 1920s, throughout Europe and in North America. It’s an astonishing evolution, when one ponders these images, and compares them with the modest and rudimentary operations that featured bottle kilns in their production – with the passage of barely 50 years.



The penultimate result of the cement-making process is called “clinker,” shown here at the point of removal from a kiln. Clinkers are about the size of a marble, and in a final step in contemporary operations are finely ground in a finish mill with a small amount of gypsum, which controls the setting time in the final product. The final cement is an extremely fine powder: one pound of cement contains 150 billion grains.



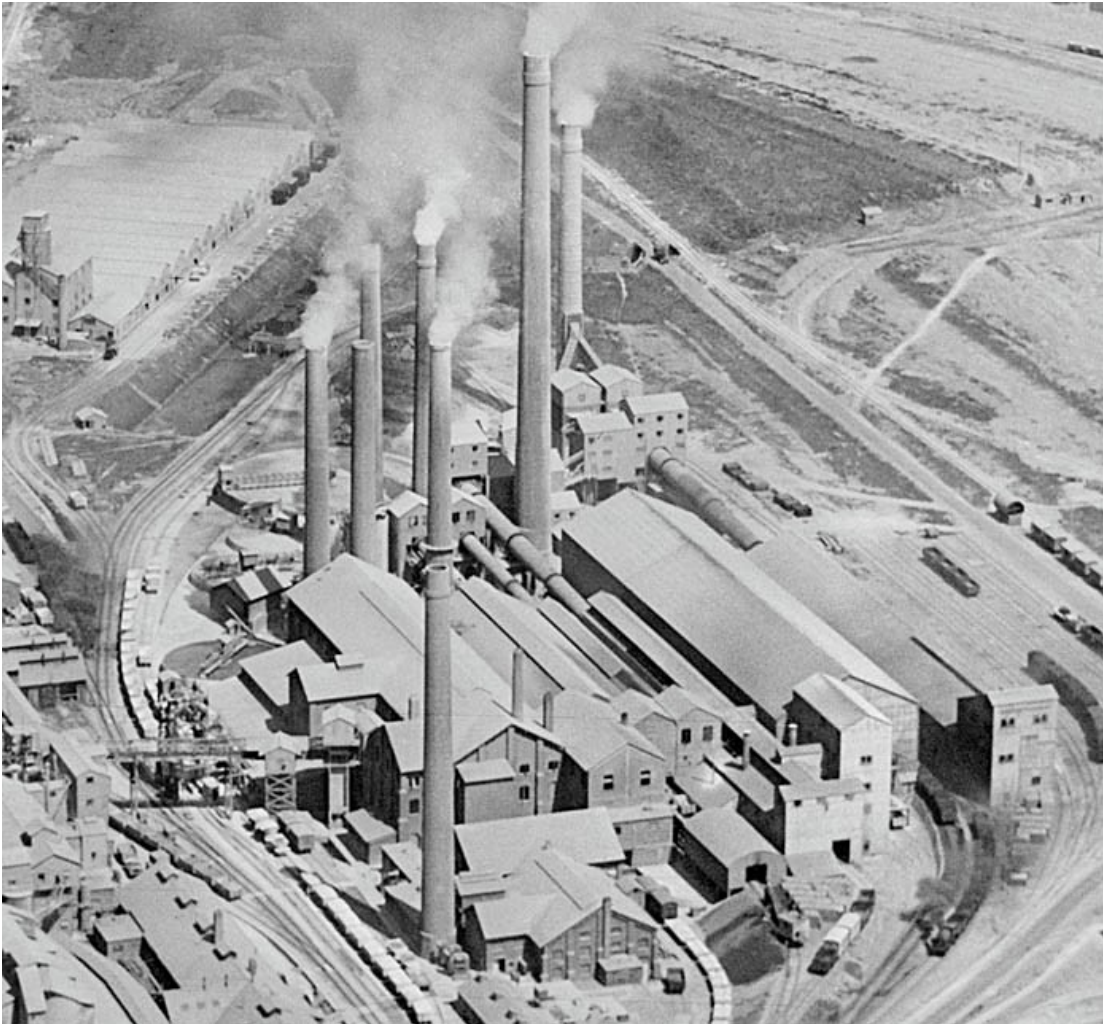
These Griffin-style roller mills, as seen in 1908, were used to grind the clinker into the necessary fine powder. Roller mills rely for their grinding effect almost entirely on the crushing effect of the weight of the wheels, seen at the base of the structures; also note the chutes and hoppers that conveyed the clinker to these machines. (Dylan Moore)



An idealized view of the pre-rotary plant at Wilmington in 1900, shows an impressive array of kiln types and ancillary cement-yard facilities: A. - 8 Batchelor kilns; B. - 12 Hilton kilns; C. - Main power plant; D. - Roman kiln bank with bottle kilns; E. - Finish mills; F. - Chalk wharf and main washmills; G. - 6 large bottle kilns; H. - Stores, maintenance etc.; I. - 8 Killick kilns; J. - Clay wharf and washmills; K. - Main cement store and packing area; L. - Offices; M. - Original Roman cement plant site. (Dylan Moore)



Oxford Cement Plant, in 1930. This operation is more understandable in terms of its layout than many other Portland cement plants, which tend to be more concentrated. Dylan Moore notes: "The plant had a simple linear design, starting with rawmills at the right-hand end, followed by slurry tanks [the large circular forms adjacent], kilns [in the long multi-windowed building, presumably rotary kilns and with twinned stacks exhausting gases, and then the various buildings in a line]: clinker store, finish mills, cement silos and packing and loading plant. The River Cherwell was in the foreground, and the quarry reserve occupied the fields behind the plant." (Dylan Moore)



View of the West Thurrock Cement Plant, which at its height produced 900,000 tons per year, making it the largest in Great Britain. Dylan Moore notes that “each kiln had its own stack, and the tallest was about 500 feet high. To the left of the kilns are the washmills, with trains of chalk lined up. A conveyor crosses the rail track carrying clinker to the open-air clinker store. The old finish mills are in the bottom left corner, at the south end of the clinker store.” While huge, this operations shows a common disposition of buildings and activities in a highly concentrated and complex situation. (Dylan Moore)

Rosendale Natural Cement

The enormous creative and productive energies being devoted to the quicklime and cement industries in the nineteenth century were not confined to England and continental Europe. As was noted above (with the Coplay operation in Pennsylvania in 1892) there were engineers, inventors and entrepreneurs in North America, who were very attentive to the local needs and the local opportunities.

In fact, there had been great interest in natural cement (as we have seen above in England), given the deposits of the same material found in major concentrations in New York State. The following information has been adapted from a monograph produced by Dietrich Werner and Kurtis C. Burmeister entitled “An Overview of the History and Economic Geology of the Natural Cement Industry at Rosendale, Ulster County, New York,” from 2006, and featured in the *Journal of ASTM International*.

Commercial production of natural cement in North America had begun as early as 1819. It was at this time that an engineer named Canvass White (1790–1834) was working on the Erie Canal (the 363-mile project that connected Albany with Lake Erie, at Buffalo, and which progressed from 1817 to 1825). In an effort to improve construction practices, in particular for the production of a material that could withstand water, he went to England to study canal construction, and learned about natural cement there. Armed with his own cement-making patent, he opened the first natural cement factory, near Chittenango, in the central Hudson Valley of northern New York State, near Syracuse. The product proved so successful that White expanded operations wherever he found the preferred variety of limestone: the clay-rich dolomite that is capable of hardening while submerged, and which was thus suited for many applications, including of course canal construction.

A completely different area of New York state, near the Hudson River north of New York City, called Rosendale, proved to have even better concentrations of dolomite limestone than Mr. White had found at Chittenango. These deposits were vast: 22 feet deep, three miles wide, and extending 32 square miles between High Falls and Kingston. The cement turned out to be so good that the term “Rosendale cement” became interchangeable with natural cement. By the early 1840s, 13 companies produced 600,000 barrels of cement annually. In the final year of the nineteenth century, Rosendale’s cement industry peaked, producing nearly 10 million barrels a year. In addition to various North American canal projects, natural cement produced at Rosendale was used in the construction of some of America’s most enduring landmarks. Thousands of public works projects, including portions of the U.S. Capitol Building, the Brooklyn Bridge, the pedestal of the Statue of Liberty, and several large aqueducts. And during this time, natural cement operations spread beyond the Rosendale area, with production in over 70 locations in the United States and in at least three in Canada (it is possible that this included the Babcock plant). But Rosendale still led the way: annual reports of the United States Geological Survey suggest that the Rosendale cement region accounted for nearly 50% of all the natural cement manufactured in North America over the course of the industry’s 100-year history.



Illustration of a barrel emblazoned on its end with the Rosendale Cement name, and noted with an illustration as “Brooklyn Bridge Brand” to remind clients of its use in that iconic structure. (Wikimedia Commons)

Another source identifies more than 70 billion pounds of natural cement mined and processed from Rosendale sites from 1818 to 1915.

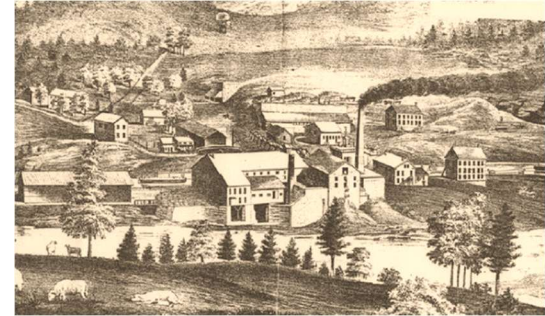
But as the new century began, builders needed even stronger cement, and Portland cement, which we have seen was well established in Britain by 1860, rapidly overtook natural cement production in the United Kingdom. And with the development of the Coplay Portland cement operation in Pennsylvania in 1893, the die was cast. Natural cement held on for a while as a specialty product through the early decades of the twentieth century, but in 1970, Rosendale's Century Cement Manufacturing Company, the last natural cement works in North America, closed. All in all, it had been a good run. Thirty-four different cement companies operated prior to 1900, a count that did not include unincorporated family businesses.

Remnants of cement operations including kilns and the Widow Jane mine are preserved in the Snyder Estate Natural Cement Historic District in the Rosendale area. While the natural cement industry was virtually lost, demand was later revived by efforts to restore historic buildings and structures using historically accurate materials. This led to the re-opening in 2004 of the historic Hickory Bush Quarry in Rosendale, operated by Freedom Cement, which currently sells authentic Rosendale cement under the Century Brand trademark.

Information from the Dietrich Werner and Kurtis C. Burmeister article concerning the various cement-production processes and technologies that we have seen above for the United Kingdom are slightly reiterated for the Rosendale operations. There are a few useful historic images, and helpful information on mining, loading and firing of the kiln, and final processing (grinding and packaging) and transportation.

Werner and Burmeister have this to say about mining: "During much of the nineteenth century, miners utilized sledge hammers, star drills, black powder, and room-and-pillar mining techniques to extract dolostone from the Rosendale deposits. Despite the eventual incorporation of technological advances such as pneumatic drills, the use of basic room-and-pillar mining techniques persisted throughout the entire course of the cement industry near Rosendale. Room-and-pillar mining is an effective technique for removing cement rock from stratified deposits by leaving a carefully arranged array of pillars to support the ceilings of excavated spaces. Elaborate tramways transferred carloads of rock extracted from mines to batteries of kilns to begin the refining process. These have been described as round kilns, constructed of brick and local rock, and we might presume that they were old-fashioned bottle kilns or perhaps chamber kilns. The final clinker of the firing was identified as a soft yellow product.

"Workers charged the kilns at their upper openings with alternating layers of fuel and dolostone. Initially, locally hewn wood was the preferred fuel. However, following deforestation of the region, coal shipped from Pennsylvania became the primary fuel. Workers carefully regulated the kilns, because if temperatures became too intense the dolostone recrystallized into a material that rendered it unsuitable as cement.



A lithographic view of a major (but anonymous) Rosendale natural cement operation. (Werner and Burmeister) The cement plant is in the middle foreground – other buildings may be imagined by the illustrator, or features of other industrial activity. Note for the cement factory the belching stack – this would have been the stack kiln in which the clinker was produced. Also note the piles of refuse placed outside the kiln area, and adjacent to the waterway. Finally, note the major building attached at the left-hand side, where cement would have been ground and then moved through the two large openings at the base of that building, to be placed in barges for transport to other warehouses or to construction sites.

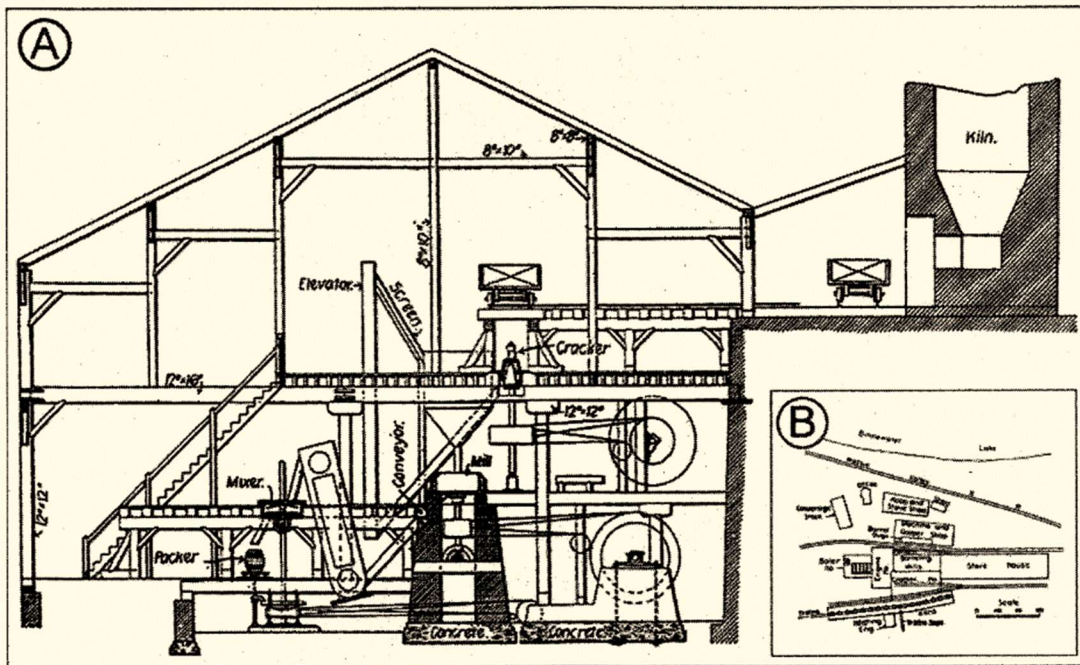
“Workers withdrew the calcined materials from the base of the kilns and removed the residue before feeding the properly burned rocks into “crackers.” The gravity-fed, coffee-mill type cast iron crackers crushed the relatively soft burned rocks into smaller fragments. Mills containing large grindstones rendered the crushed and burned rock fragments into a fine-grained powder. Workers discharged the resulting powder directly into paper-lined, wooden barrels commonly manufactured in on-site cooper shops. Each finished barrel contained approximately 300 pounds of powdered natural cement. Manufacturers used the Delaware and Hudson Canal and the Hudson River to transport their products to market.”



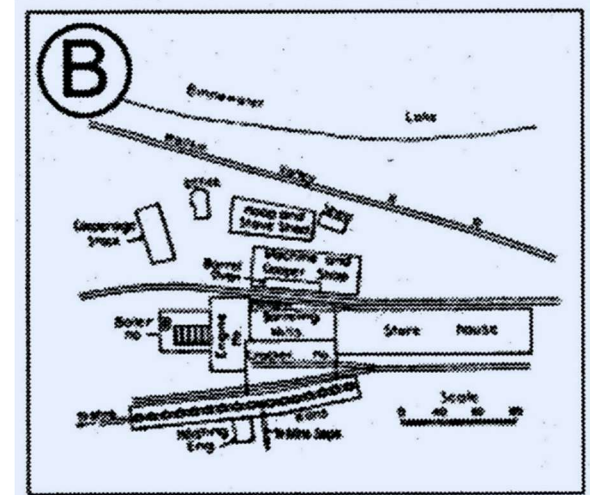
This image is thought to show one of the Rosendale natural cement operations. (Wikimedia Commons) Note the two stout stone kilns and the steeply-angled ramp used to move raw material via carts into position. Also note the housing atop the kilns, presumably where workers would tip the carts and then pour contents into each kiln mouth. A shed-roofed passage at the base of the kilns led to the three-storey processing site – presumably for final grinding and bagging. The tall stack in the right-hand distance would have been used to exhaust the various pieces of machinery inside.



This photographic view of the Consolidated Cement Works at Rosendale reveals first, in the foreground, the enormous stacks of wood needed in the firing of the shaft kiln, the major vertical element seen at right-hand side. Tall metal chimney stacks rise from various areas of the operation. It is presumed that the natural cement mine was situated in the steep hillside. (Werner and Burmeister)



The Werner and Burmeister article includes a useful technical image focusing on the Lawrence Cement Company plant at Binnewater. This cross-sectional drawing shows the lower-most area of the kiln, at right, and at a higher level than main part of the building. It has access for the burned cement via an upper opening, where carts of burned stone were moved to sit above a “cracker.” Other features in the plant identified on the drawing are a screen, elevator, mixer, conveyor, mill and packer. While not labelled, the two large circular elements on the right-hand side would have been part of the power drive that operated all of the machinery. Their caption advises to note the relative position of kiln, cracker, grinding mill and packing area; it also notes that the tramways atop the kiln leading to mines are not shown. So obviously the authors were more interested in this building – what they are calling the kiln battery and mill structure – where the clinker is cracked, ground, conveyed and packed.



An inset site plan of the Lawrence Cement Company drawing. Even though the labels are very difficult to make out, it is clear enough to identify Binnewater Lake at the top, the Hudson Valley RR line below that, and then several other rail spur lines traversing the site. Texts identifying several of the buildings in the centre of the plan are also fairly legible, from left to right: Boiler, Engine House, Burning Units (kilns presumably) and Store House. A building set above these key structures appears to be labelled Machine and Cooper Shop (where the barrels for final cement preparation were made). Other labels are illegible. The scale reference appears to read 0-40-80-100 feet.

Queenston Natural Cement Works

By the late 1800s, Canada had its own small natural cement industry, active near Queenston Ontario for nearly 20 years, from 1885 to 1904. An on-line summary of that operation, developed by Harold Usher, provides this useful information, with modest editing for clarity: "In the 1870s Isaac Usher was a masonry contractor, working on the third Welland Canal [a system that connected lakes Ontario and Erie]. During the canal excavation it was discovered that a layer of natural cement rock underlay the blue dolomite under much of the Niagara Escarpment. In 1885 William Hendershot leased a portion of his Queenston Quarries, where the layer of cement rock was six to ten feet in thickness, to Isaac Usher. The latter established his cement plant about one quarter mile east of St. David's under the title of "Isaac Usher & Son." Three kilns, later increased to six, were constructed on the face of the escarpment. They were built of rubble stone, roughly shaped, about ten feet in diameter and forty feet high. These were lined with fire brick and fire clay, and the grates at the bottom were steel railroad rails cut into convenient lengths. The mill was steam operated and located at the base of the kilns, so that no material would have to be lifted. The warehouse was located at the bottom of the escarpment on the south side of the Michigan Central Railway on a siding from the main line. The cooper shop for the making of barrels was built on the north side of the railway line immediately opposite the warehouse. Each barrel contained 350 pounds of cement. The ground or finished cement was transported from the mill to the warehouse by means of a conveyor belt and chute, and all handling from the raw cement rock to the finished product was by gravity.

"Since only one layer of the sedimentary rock was being used, it was more economical to tunnel it rather than attempt to remove the heavy overburden of many feet of limestone. Four tunnels were driven into the escarpment, eventually totalling a length of between six and seven miles. Drilling the tunnels was done by steam drills. Dynamite was used on account of its shattering effect, and picks, wedges and striking hammers were used to break up pieces that were too large to lift into the mine cars. Light-gauge steel rails were laid following the advance of the tunnels, and the mine cars were hauled to the kilns by ponies or small horses. Large pillars of unexcavated rock were left to support the roof, and timbers were used to shore up the roof in necessary spots.

"Firewood and soft coal were placed on the steel rails at the bottom of the kilns, and then alternate layers of cement rock and soft coal until the kiln was filled. The fires were then lighted and kept burning around the clock, pouring out black smoke across the landscape. The grates at the bottom of the kilns were shaken daily, and the ashes or cinders were placed on a conveyor belt to the mill. As the contents of each kiln subsided more coal and cement rock were added from the top, and it was a continuous process.

"The millstones [used in the grinding process] were made in France of French burr stone, which was extremely hard, but even so, it was necessary to re-dress them at least once a year to maintain the

sharp edges of the grooves. The bottom stone was stationary, and had grooves cut from the centre to the edges. The upper stone revolved, driven by a steam engine, and its centre was cut out, leaving a hole through which the burned cement rock was poured. As the upper stone revolved the ash or cinder was ground into a fine powder, and as it fell from the outer edges of the stones, it was collected and conveyed to the warehouse below. Here it was packed into barrels made on the spot, and either loaded into railway box cars or stored for future shipment. Two or three years before the plant closed, heavy paper bags came into general use, replacing the barrels. These bags held 87 1/2 pounds of cement, or one-quarter the weight of a barrel. The business employed about thirty men, and the output averaged 250 barrels per day.



“In 1904 Isaac Underwood was forced to close the cement works. Natural cement could not compete with the new "Portland" type which came into use at the beginning of this century [in Canada]. Although of very high quality, it took about 24 hours to set, whereas Portland took only six, and was preferred by contractors and builders as it greatly speeded their production. During its operation the Queenston Cement Works supplied cement to the Sault Ste. Marie and St. Lawrence canals, as well as the usual building trades.”

Usher Natural Cement Plant, St. David's, 1904 (Alan Clifford Collection, Niagara-on-the-Lake Public Library). It is presumed that the structures at the top of the hill (there appear to be two of them visible), with the men assembled at their edges, were the natural cement kilns. Other buildings, which were placed in succession to exploit the natural slope of the site, would have housed grinders, and then via the long chute, the final destination for the material: the bagging (or barreling) warehouse set beside a railway track.