troublesome part of a kiln this may be an important advantage in the use of removable arches.

Down draft kilns are built in the rectangular and circular forms. The same principles of design are applied to each form. The floors should be above ground level and underlain by fairly large shallow flues to avoid dampness and high fuel consumption. The flue system should extend to all parts of the floor with equal frictional surface so as to have uniform heat distribution over the entire floor, and connect with exterior stacks to save loss of interior space. The floors, preferably as solid as possible, are perforated to allow the gases to enter the flues freely. The stack should be adequate to furnish a good draft during the early stages of burning when the fires are low, and equipped with proper damper arrangements to give entire control of the draft.

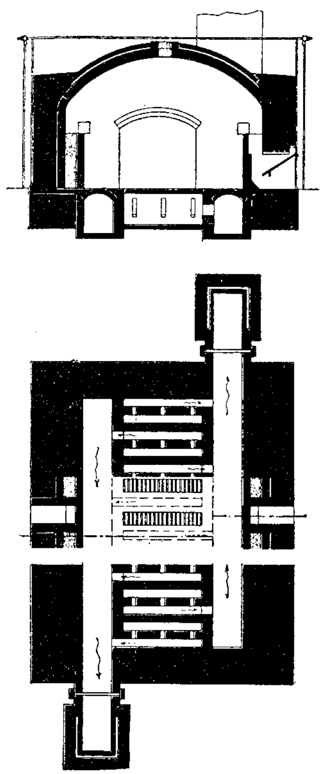
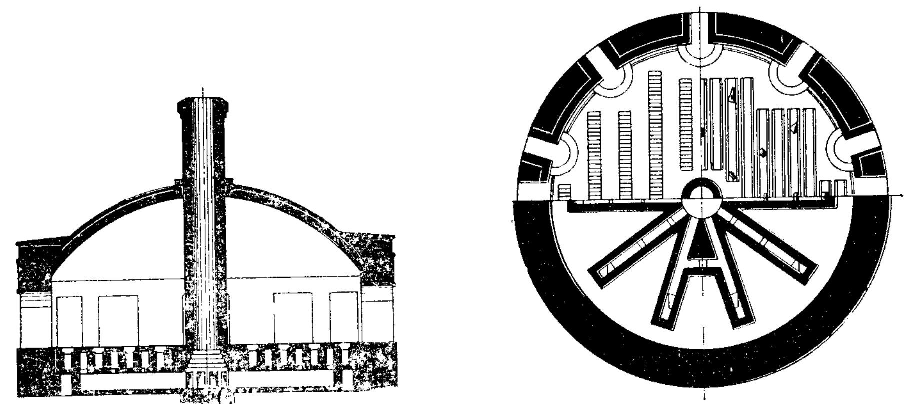


Figure 26.—Rectangular down-draft kiln. (After Lovejoy.)

The circular kilns are cheaper to build and to keep in repair, and are more economical of fuel than a rectangular kiln of the same floor area because of a proportionately less wall area. Also the draft distribution is better in a round kiln because the wall is equidistant from the center at all points. The ends and corners of a rectangular kiln are difficult to heat properly because of poor draft and a relatively greater area of wall surface.

The rectangular kilns (Fig. 26) can be built of larger capacity and permit better yard arrangements and easier setting of the ware. For brick and tile these latter considerations are of relatively less importance and the round kilns are preferred. For burning roofing tile and similar ware that is more difficult to set in the round kilns, the rectangular kilns are preferred and are rapidly replacing the round kilns.[1]

In the case of round kilns no advantage is offered by multiple stacks because the draft distribution can be made as nearly perfect as is practically possible by a proper flue system. With rectangular kilns which are usually much longer than wide conditions are much different. In general, the advantages in favor of one stack for a circular or square kiln can be retained in long rectangular kilns by dividing the floor into squares, each of which has a stack and complete flue system of its own. When the stacks are more frequent than one per unit square of floor space as just described, the kiln is said to have multiple stacks.



a. Verticle Section b. Floor Plane showing collecting flues

Figure 27.—Center stack down-draft kiln. (After Lovejoy.)

Center Well Flue Bottom. Round kilns are commonly built with a *center well* under the center of the floor from which collecting flues radiate to collect the gases from the floor flues above. Figure 27a shows such a round kiln in section with a center stack rising from the center well.[2] The lower half of figure 27b shows the plan of the collecting flues, the upper right sector shows the plan of the floor flues and the upper left sector the floor spacing. Ten furnaces are shown in the outer wall of the kiln. The center stack gives a cheap construction and strong draft during water smoking but takes up valuable space in the kiln, and interferes in setting. The same flue system is widely used with outside stacks, the gases being drawn off from the bottom of the well. As no inside stack is to be considered, the wells can be made larger

[1]Worcester, Man. of Roofing Tiles, Geol. Survey of Ohio, Series IV, Bull. 11, p. 399 (1910).

[2]Montgomery, Trans. Am. Cer. Soc. 13, p. 311 (1911) shows drawings, sections, etc. of center stack down draft kilns used in a continuous system.

and the inlets correspondingly larger or more numerous as indicated in figure 29. The principle of this construction is that the draft should be

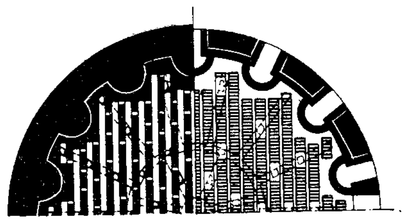


Figure 29.—Flue system of center well kiln. (After Lovejoy.)

greatest in the center because of the greater distance from the furnaces.

The gases from the fires are led up toward the crown of the kiln in

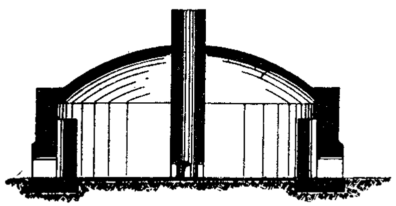


Figure 30.—Down-draft, center stack, solid floor kiln, showing location of bag walls. (After Lovejoy.)

"bags" as indicated in figure 30. This is done to prevent the hot reducing flames from striking the ware directly.

Cross Head Flue Bottom. Cross head flues in which the collecting flues lead into a cross head laid as a diameter of the round kiln instead of into a center well are also in common use. (Fig. 28.)

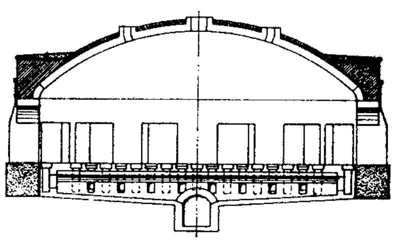


Figure 28.—Cross head flue type of kiln bottom. (After Lovejoy.)

The Detroit Roofing Tile Company formerly operated a *Mitchell rectangular down draft* kiln 14 feet wide by 56 feet long and ten feet high, the flue system of which represents the same principle as applied to rectangular kilns. Figure 31* explains the general features of con-

*Worcester & Orton, Manufacture of Roofing Tiles, Geol. Survey Ohio, Series 4, Bull. 11, p. 405 (1910).

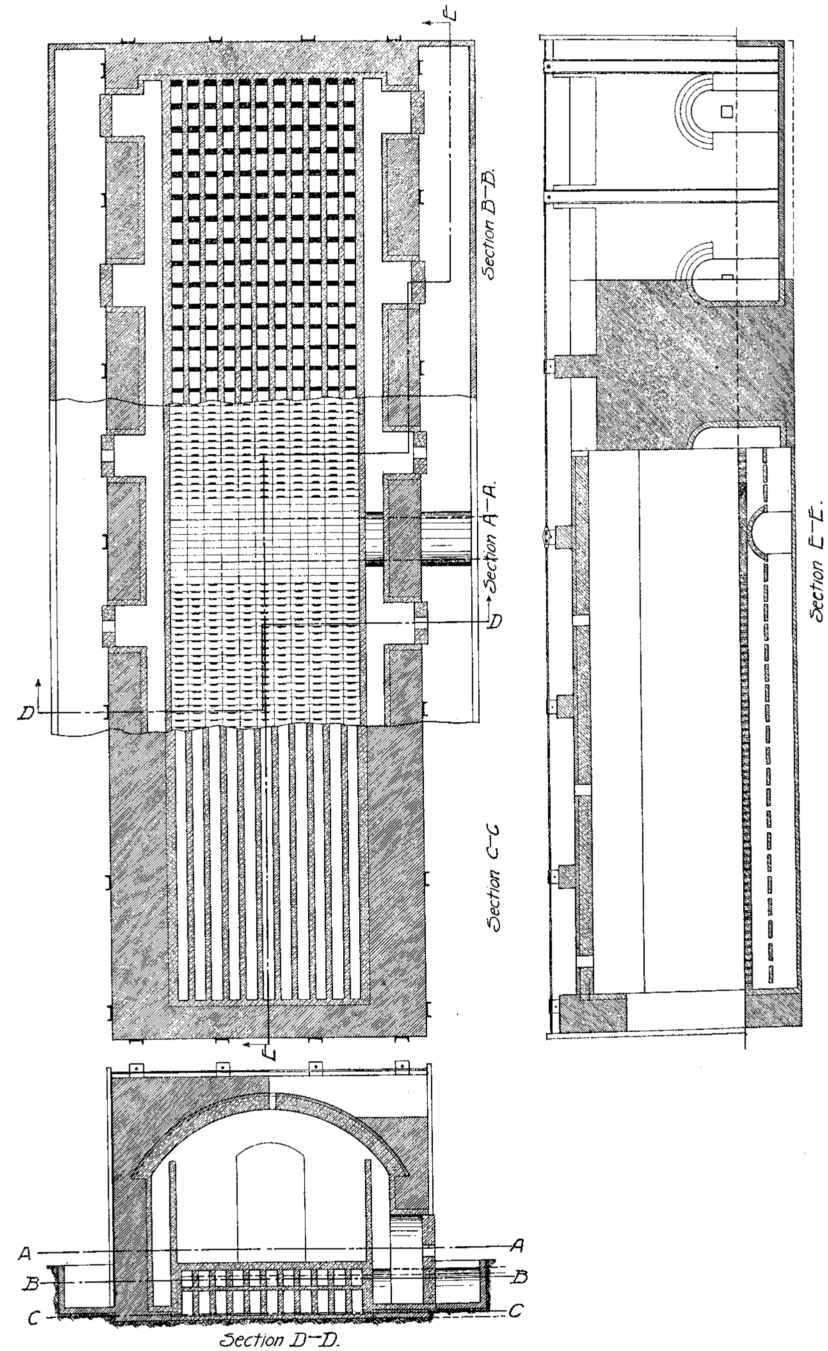


Figure 31.—Mitchell down-draft rectangular kiln. (Ohio Geol. Surv.).

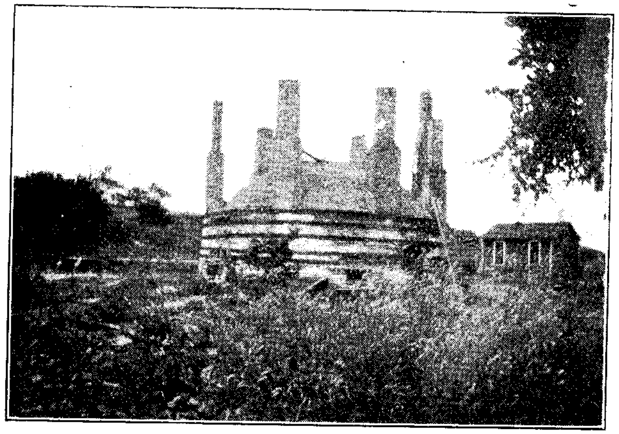


Plate XXVI, Figure 1.—Eudaly kiln, St. Louis Tile Co., St. Louis, Gratiot County.

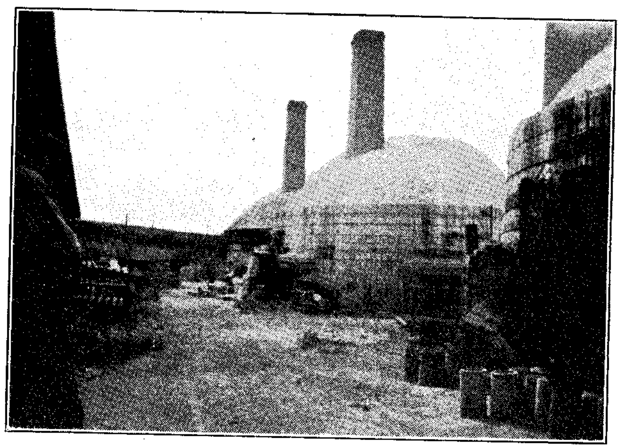


Plate XXVI, Figure 2.—Wheeler kilns, St. Louis Tile Co., St. Louis, Gratiot county.

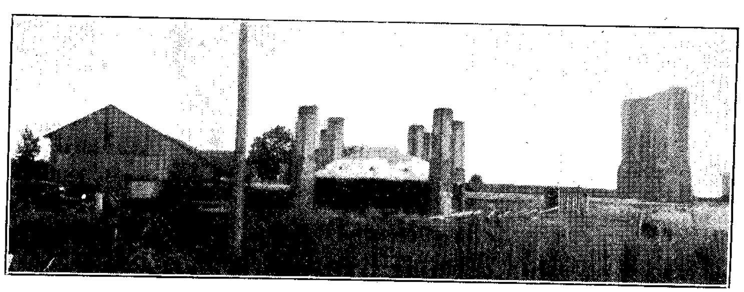


Plate XXVI, Figure 3.—Kiln, tunnel dryer, and shed, Shields Bros., Kalamazoo.

setting is more complicated as floor flues have to be made in the setting to obtain satisfactory draft conditions.

Eudaly Kiln. The Eudaly kiln figure 32 is a multiple stack kiln introduced as a patented kiln and extensively sold on the yard right plan. It was built round and rectangular. The bottom is divided into sectors

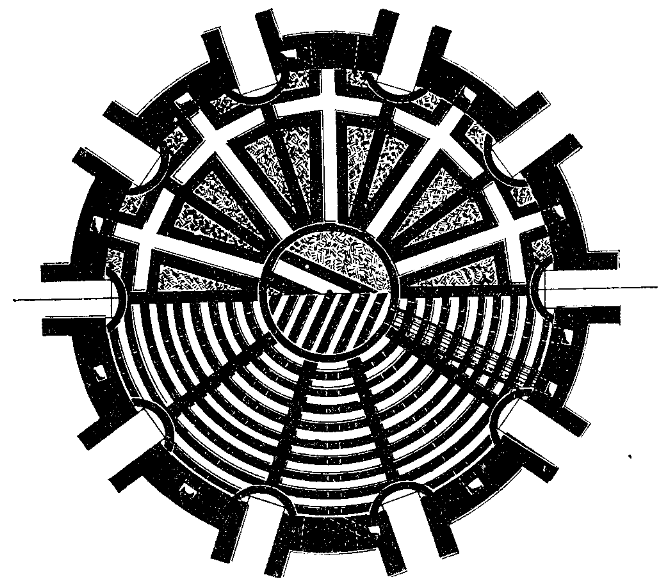


Figure 32a.—Flue system of Eudaly multiple stack kiln. (After Lovejoy.)

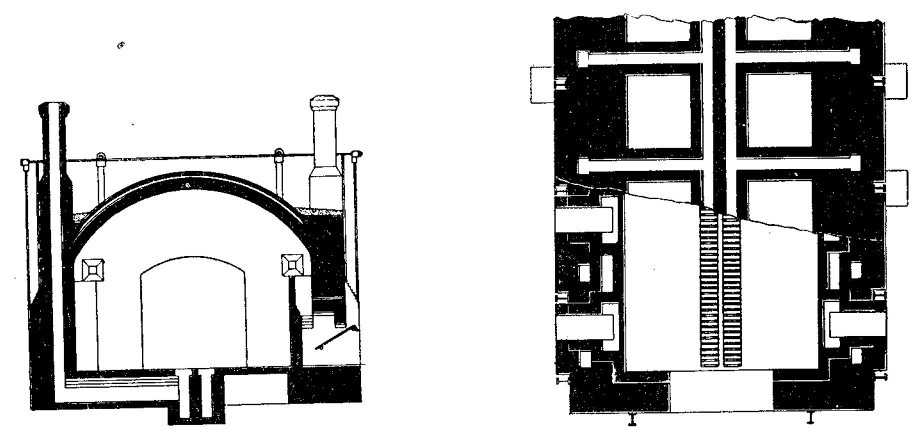


Figure 32 b and c. Section and plan of rectangular Eudaly kiln. (After Lovejoy.)

corresponding to the furnaces, each sector supposedly controlled by an individual wall stack. In the round kiln the center is also controlled by an individual stack. The stacks connect with flues running radially toward the center, or in the rectangular kiln straight through the center of each section to the center wall. The bottom of the stack and the flues are on the same level, about 3 feet below the floor. The entire sector or section is covered with small 4 inch mid-feather walls about 5 inches apart as in the lower part of the figure. These feather walls cross the flue which is about 18 inches deep by arching or lapping each course until the gap is bridged, and are covered with perforated brick which allow the gases to pass through the floor with perfect freedom. The hot gases then take the shortest route to the stack leaving the area farthest from the stacks and near the dividing walls stagnant.

To get a more substantial bottom and semi perforated or solid floor the flue system has been modified as shown in the upper half, figure 32a. In order to allow the kiln to be operated on the up-draft principle during water smoking, the radial flues were extended through the kiln walls and boxed in outside the walls. By closing all stack dampers, furnace doors, and ashpits, opening the crown vent and using the open ends of the radial flues as furnaces or air inlets, the operation was up-draft for water smoking or cooling the kiln.

The old Eudaly kiln on the property of the St. Louis Tile Co., Gratiot County (Plate XXVI) is 25 feet in diameter and divided into 5 sections and a center, each equipped with a separate stack. The draft was found inadequate and the sector stacks were raised by about 5 feet while the stack connecting with the center on the side of the kiln was raised about 10 feet. As the land is low the poor draft was probably largely due to moisture or water in the kiln bottom.

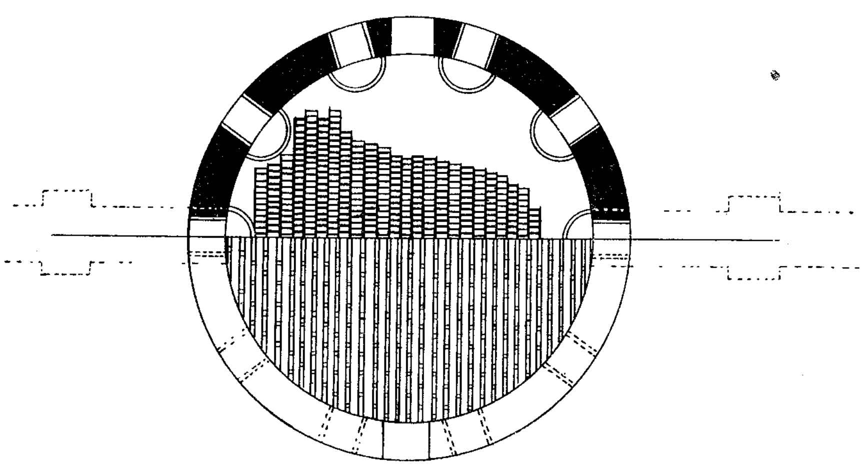


Figure 33.—Flue system of Wheeler kiln.

Wheeler Kiln. A kiln bottom introduced recently in the construction of kilns for 3 Michigan tile plants consists of parallel rows of feather walls 4 inches wide, about 5 inches apart as shown in the lower part of figure 33. The flues are connected by small openings in the lower parts

of the feather walls as indicated, the hot gases passing down between the feather walls and through the small holes to the left or right and up the stacks. The kilns are laid out in a row with a stack between each kiln and on each end of the row. The St. Louis Tile Co. has a row of four of these kilns and five stacks. In firing the kiln the hot gases take the course of least resistance down the left and right sides of the kiln to the main flue and up the stacks. Even if the holes through the center feather walls were large enough to pass a normal amount of gas without excessive friction losses, the holes through the last feather walls near the stacks are entirely inadequate to pass the large volume of gas from the 10 furnaces of the kiln. With these kilns it was impossible to obtain hard burned tile except in the upper courses even when 30 to 50 tons of coal were used in firing. The kilns are remodeled as shown in figure 34

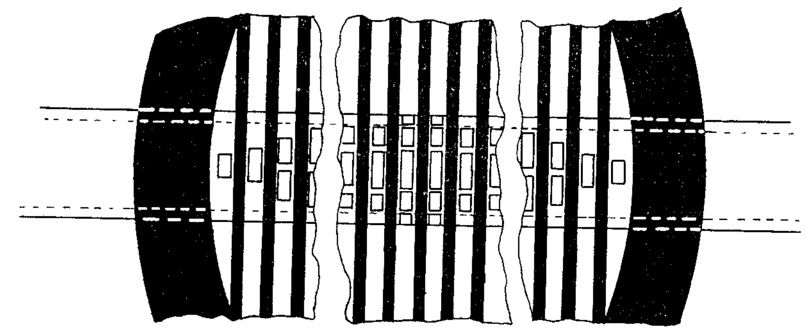


Figure 34.—Modified flue system of Wheeler kiln.

by knocking out the lower center of the feather walls, and running a flue through the center of sufficient capacity to handle all the gases. In order to overcome the tendency of all gases to pass down the sides of the kilns, the openings into the large cross flue are much larger in the center of the kiln than at the sides. In this form the kiln bottom is similar to the cross head flue system except that the gases are removed at the ends of the cross flue instead of at the proper place, the center. These rebuilt kilns are giving much better service; hard burned tile are obtained from all courses except the lower three, with 12 to 15 tons of coal. All of the Michigan plants that have been afflicted with kilns of this original design have failed.

The flue system in the kiln bottom must be correct if the kiln is to be successful.* Other factors may make a kiln a failure but nothing can compensate for an incorrect kiln bottom in determining heat distribution, not even forced draft.

This same plant near St. Louis, Gratiot County, is also troubled by another serious mistake in kiln construction. In order to make the kilns easy to set, the floors of the kilns are set on the level of the yard. This

[1] See T. W. Garve, Trans. Am. Cer. Soc. 14, p. 113 (1912), for diagrams of kiln bottoms.

in itself would cause no trouble, but the land is low and swampy, so that the flues in the kiln bottom which is frequently about three feet below grade, are frequently filled with six inches of water. Water in the bottom of a kiln is a serious cause of trouble.[1] The evaporation of the water greatly increases the fuel consumption, kills the draft, makes steam on the ware, and prevents a good burn of the bottom courses. Even when the soil appears perfectly dry a good concrete foundation, well drained, is more than worth the additional cost, because capillary action of the kiln brick tends to draw moisture from the soil, keeping the kiln bottoms moist.

Summary. The water smoking period in the usual down draft kiln is unnecessarily long because the stack is cold and exerts no draft. Under these conditions the only means of forcing the air and heated gases through the ware is by the buoyant force of the hot gases in the bags, which is inadequate for this purpose. The use of a fan to draw the gases through the kiln (forced draft) entirely overcomes this difficulty.[2] Frequently it is possible to build the kilns so that three or four are connected to one stack. By proper planning it is then possible to start water smoking a cold kiln with a hot stack. With some kilns that have deep flues and high furnaces it would be worth while to build a small fire in the base of the stack to create a draft for this purpose if forced draft is not available.

Oxidation is accomplished by firing rather lightly with a good draft to draw in a large amount of excess air for oxidizing the ware. This condition is contrary to that necessary for efficient uses of the heating value of the fuel, but is demanded by the clay which must be oxidized before it can be properly vitrified. In many pottery or porcelain kilns reducing atmosphere is desirable just before the ware is matured to leave the iron in the ferrous condition so as to prevent dissolving the ware to a yellow cast instead of pure white.

Small kilns generally have a more even distribution of temperature than large down draft kilns. The highest temperature is at the top center of the kiln where all the hot gases tend to accumulate[3] and the lowest temperature is at the bottom. One of the most important and difficult phases in firing a downdraft kiln is to force these hot gases down to the bottom of the kiln so that the bottom of the setting may be burned as well as the top without overburning the top. About the only way to accomplish this even temperature distribution is by means

[1] Karl Langenbeck, Trans. Am. Cer. Soc. VI, p. 22 (1900).
[2] R. K. Hursch, Clay Worker 72, p. 322 (1919).
D. Taylor, Brick and Clay Record 65 (1), p. 31 (1924).
R. F. Geller, J. Am. Cer. Soc. 4, p. 375 (1921).
W. W. Ittner, ibid. 5, p. 721 (1922).
[3] H. G. Schurecht, J. Am. Cer. Soc. 6, p. 831 (1924).
W. Carman, Trans. Am. Cer. Soc. 13, p. 117 (1911).

of a balanced draft at the fire doors.[1] After the firing has been rapid under a heavy draft for some time and the top of the kiln is at the desired maximum temperature, the stack damper is partially closed so that the fires almost smoke out around the feed holes. This checking of the draft after the top of the kiln is burned is necessary to prevent overburning the upper part of the setting and also builds up a greater positive pressure at the top of the kiln, causing a lower "free surface" (bottom) of the hot gases in the kiln. This means that the kiln tends to fill up with hot gases from the top down as the damper is closed, just as if water were being poured into a pail which had a hole in the bottom, the smaller the hole the higher the free surface "top" of the water in the pail.

The progress of burning is generally judged by the burner from his past experience, although it can be told more exactly by records of thermocouple readings or pyrometric cones when properly used. Another method is to measure the settle or shrinkage of the ware in the kiln. The ware shrinks as the burning proceeds until the product is completely vitrified. The settle may be measured from the top of the kiln in a number of ways.[2] There are also instruments available to aid in this determination. The measure of settle is, however, applicable only to the last stages of burning. Temperature measurement by thermocouples is of value in all stages from drying through vitrification.

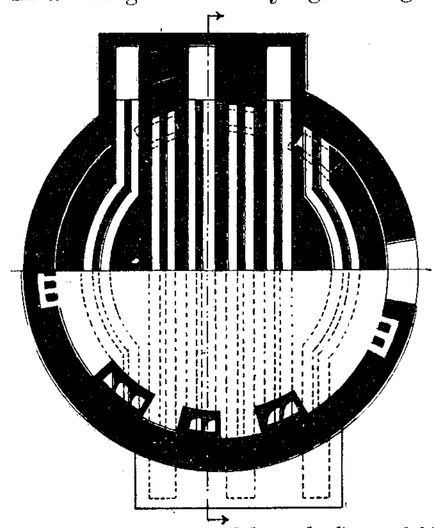


Figure 35. Stewart up-and-down draft round kiln. (After Lovejoy.)

Up-and-down Draft Kilns. There have been a number of *up-and-down draft kilns* developed with the idea of giving a better burned product

[1] Anton Vogt, Clay-Worker, 83, p. 30 (Jan. 1925).
Ellis Lovejoy, Clay-Worker, 78, p. 346 (1922).
[2] L. E. Barringer, Trans. Am. Cer. Soc. 7, p. 809 (1905).
Ellis Lovejoy, ibid. 7, p. 422 (1905).

in the lower tiers than do the simple down draft kilns. The chief difficulty with them has been that the ware in the bottom was subjected to the maximum flame temperature and over burned or at least discolored. They will heat faster but have not shown sufficient merit over the simple up-draft or down-draft kiln to be generally adopted.

Stewart Kiln. The Stewart kiln was first designed and generally built as a round kiln as shown in figures 35, 36. The furnaces are on

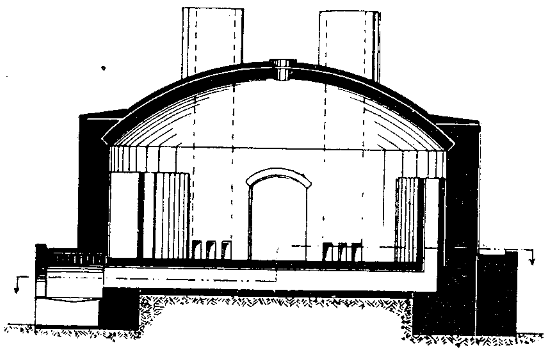


Figure 36.—Stewart up-and-down draft kiln. (After Lovejoy.)

opposite sides of the kiln and staggered so as to be in line with the proper combustion flues, two of which lead from each furnace under the floor of the kiln and up a bag on the opposite side. The floor system consists of alternate pairs of flues carrying gases in opposite directions. The furnace gases pass across under the kiln floor, which is solid, up the bags, down thru the ware, and into the stacks thru openings on the kiln floor.

The ware in the lower quarter of the kiln is burned by heat conducted through the floor, and the ware in the upper part by the down flowing gases. These gases take the easiest path, which is down the sides of the kiln, leaving the center part under burned unless the ware is set to provide flues from the outlets to the center of the setting. This feature is decidedly objectionable, especially for drain tile for which the kiln was largely used.

When applied to rectangular kilns the original type of construction may be improved by a gas flue underlying the floor between every other combustion flue as shown in figure 37. These flues are covered by perforated brick or spaced brick so that the draft may be adjusted at different distances from the sides. Each flue is blocked in the center and leads into a stack at each side of the kiln.

The main claim for this kiln, is that it is possible to burn the bottom as hard as the top without effort, and, as the bottom of the kiln warms up first the ware in the lower part does not sweat or become kiln marked

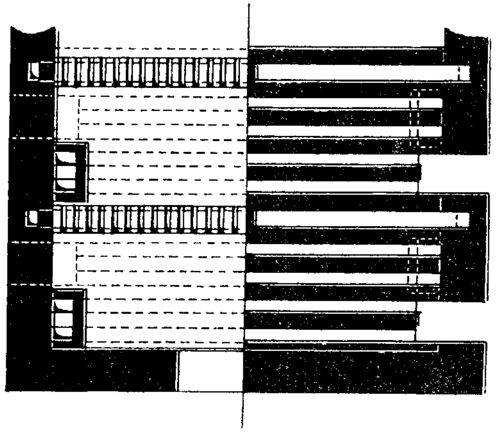


Figure 37.—Modified Stewart rectangular kiln. (After Lovejoy.)

or scummed, due to condensation of water, and the fire gases during water smoking. The draft distribution is poor unless the original flue system for discharge of gases is modified. Considerable heat is lost from the combustion flue into the ground, and when firing to moderately high temperatures the throats to the underground flues will burn out due to the heavy fire that must be maintained in the furnaces to carry the heat under the floor and up the bags on the far side. For these reasons the fuel consumption is high and the floor is apt to fail.

The *Grath solid bottom* kiln is really a Stewart kiln with an additional

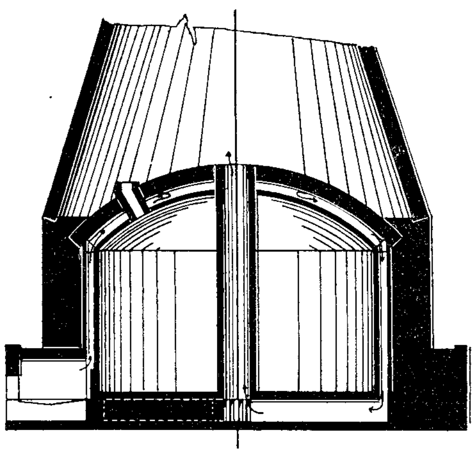


Figure 38.—Muffle kiln. (After Lovejoy.)

bag for each furnace on the near side of the kiln so that part of the fire gases reach the top of the kiln without passing under the floor. In this respect it is an improvement.

Muffle Kilns. Muffle kilns are used in burning terra cotta, enameled brick, and all wares which must be protected from contact with the furnace gases. It is evident that the muffle walls which surround the ware and protect it from the fire gases must be as thin as possible, and the arrangement of flues such that the muffle is encircled completely by the hot gases. Otherwise fuel consumption will be excessively high as most of the heat in the gases will pass up the stack. Figure 38 shows an intermittent up and down draft muffle kiln. All muffle kilns are closed top or crowned. The same figure also gives an idea of the ridiculously large and expensive stacks used on many pottery kilns, the base of the stack being large enough to contain the entire kiln.

All round kilns must be carefully banded, and rectangular kilns carefully stayed, to prevent buckling of the kiln due to expansion and contraction as the kiln is heated and cooled.

Furnaces. The furnaces should be built so that they can be readily repaired or rebuilt without tearing out the wall of the kiln. This is best done by making an outer arch to support the kiln wall and a separate inner arch of first class fire brick which can be replaced without disturbing the outer arch. Building the arches in this way of arch brick instead of wedge brick also allows for the shrinkage of the fire brick, making less repairs necessary.

Furnaces[1] are in many ways an important part of a kiln and largely determine the economy and success of the burning. There are two general types of furnaces, the flat grate[2] (Fig. 39c) such as found in boiler furnaces, and the pit or inclined grate.

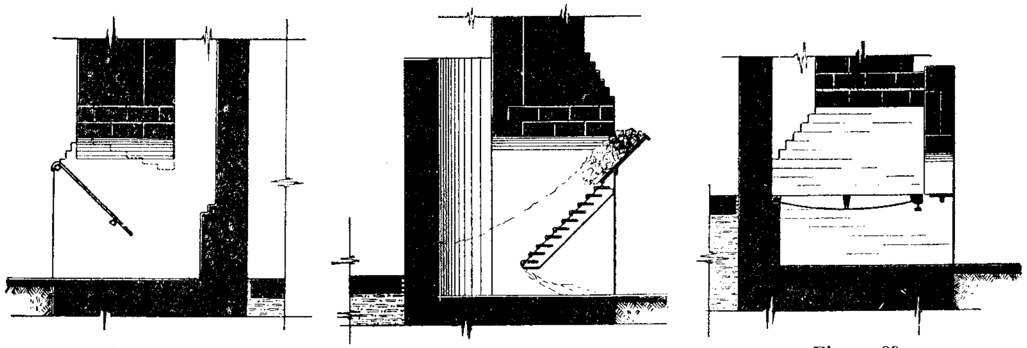


Figure 39a. Figure 39b. Figure 39c.

Figure 39a, b and c.—Pit and flat or horizontal grate furnace. (After Lovejoy.)

The pit furnace in its most common form (Fig. 39a, b) is widely used throughout Michigan. The grates are usually flat bars of iron hooked over a bar at the mouth of the furnace and set at an angle varying from 30 to 60 degrees. In this form the furnace acts much as the original Siemens gas producer.

[1]P. Frion, Ceramique 25, 1, p. 158.
[2]A. J. Aubrey, Trans. Am. Cer. Soc. 9, p. 717 (1907).

The coal is fired at the top. The primary air enters through the ash below the grate and through the grate. The secondary air is controlled by partially or completely closing the fire opening with coal. As the coke in the pit is consumed the coal on the bar slips down or is pushed down before charging a fresh supply of coal. In this way the coal passes through the distillation, reduction, and oxidation zones.

Sometimes these pit furnaces are built with a solid plate of brick work or fire clay, instead of the iron grate bars. This construction allows better air control than the iron bars.

Although the usual construction is with a straight horizontal arch such as shown, stepping down the arch is indicated in dotted lines, or a simple drop arch on the inner ring forces the air down and insures better mixing with the combustible gases.

From the standpoint of good burning when natural draft is used, the grates should be below the floor level of the kiln, so that the buoyant force on the hot gases in the bags will be sufficient to drive the hot gases from the top of the kiln down through the ware, forcing the cold air out through the cold stack. This is particularly important during the early stages of burning or water smoking. However, firing is difficult if the grates are below the yard level, and handling the ware requires more work if the kiln floor is above the yard level, so that a compromise is frequently made by placing both kiln floor and ash pits at the yard level.

Lovejoy[1] says furnaces should be not over 36 inches wide or longer than 48 inches for efficient operation. It is better to increase the number of furnaces rather than the size. The flat grate area should be about 1.5 per cent of the cubic setting space in the kiln when burning to cone 1. This area should be increased about 0.05 per cent for each cone above 1. Pit furnaces should be about two-thirds the size of the flat grate furnaces.

The practical rate of combustion varies from about three to five or six pounds of coal per hour, per square foot of flat grate area when burning closely set ware to about seven to nine pounds of coal per hour per square foot when burning hollow ware such as sewer tile that offers much less resistance to the flow of gases than closely set brick. At times these rates may be exceeded.

It is practical to use automatic stokers in furnaces set in periodic kilns[2] and in kilns of other types. Automatic stokers mean more even firing, better control, and fuel economy when properly adapted to ceramic furnaces. The advantages of mechanical stokers has long been recognized in power generation but the ceramic industry has been slow to adopt modern methods, particularly from other industries.

[1]Burning Clay Wares, p. 146, T. A. Randall, (1920).
[2]J. D. Martin, J. Am. Cer. Soc. 6, p. 1044 (1923).
Steinhoff, ibid. 6, p. 268 (1923).

Heat balances of periodic kilns[1] show from 5 to 20 per cent of the heating value of the coal actually used to burn the ware. Average conditions[2] are probably represented by about 12 per cent of the heating value of the coal actually used to burn the ware.

CONTINUOUS OR REGENERATIVE KILNS

In the ordinary periodic kiln the waste of heat energy, and therefore of fuel, is enormous. The gases leave the kiln at a temperature about the same as that of the ware in the kiln and all of this is lost. At the end of the burning a large amount of heat is absorbed in the ware and kiln, which is usually thrown into the atmosphere during cooling. Some plants use a part of this latter heat for drying, so-called waste heat drying, but even then a large amount of it is lost.

The continuous or regenerative kiln aims to eliminate both of these losses by absorbing the heat from the hot gases in water smoking and oxidizing the brick, and absorbing the heat from the burned ware in the air used to oxidize the fuel, so that only a small amount of fuel is needed to raise the preheated air and preheated ware to the temperature required for burning.

There are two important types of continuous kilns. In the first type the *ware is stationary and the fire moves through the ware.* These kilns may be Tunnel or Chamber kilns. In the second type the *fire is stationary and the ware is pushed through the fire.* These are called the Car Tunnel Kilns.

Tunnel Kilns. The first continuous ring kiln was patented by Arnold in 1839. The Hullman kiln patented in 1854 has an annular tunnel or ring, inclosing an annular smoke flue with the stack in the center. Hoffman and Licht patented the Hoffman kiln in 1854. This was the first successful continuous kiln and is of the continuous tunnel, horizontal draft, direct heat, closed or crown top types.

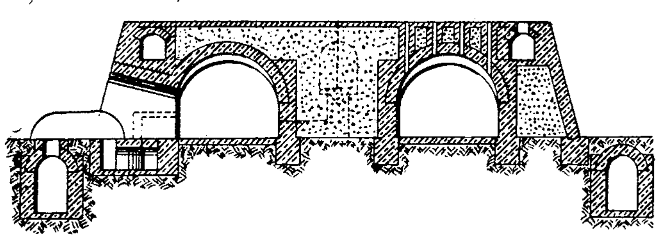


Figure 40.—Cross section of modern Hoffman kiln. (After Lovejoy.)

Hoffman Kiln. A modern Hoffman kiln is shown in cross section in figure 40, and plan in figure 41.

[1]A. V. Bleininger, Trans. Am. Cer. Soc. 9, p. 412 (1908).
Harrop, J. Am. Cer. Soc. 7, p. 35 (1918).
F. B. Ortman, J. Am. Cer. Soc. 4, p. 669 (1921).
L. Vielhaber, Keram. Rundschau 27, p. 293 (1919), J. Am. Cer. Soc. 3, p. 83.
[2]Report of Committee Refract. Man. Ass., T. Am. Cer. Soc. 5, p. 602 (1922).

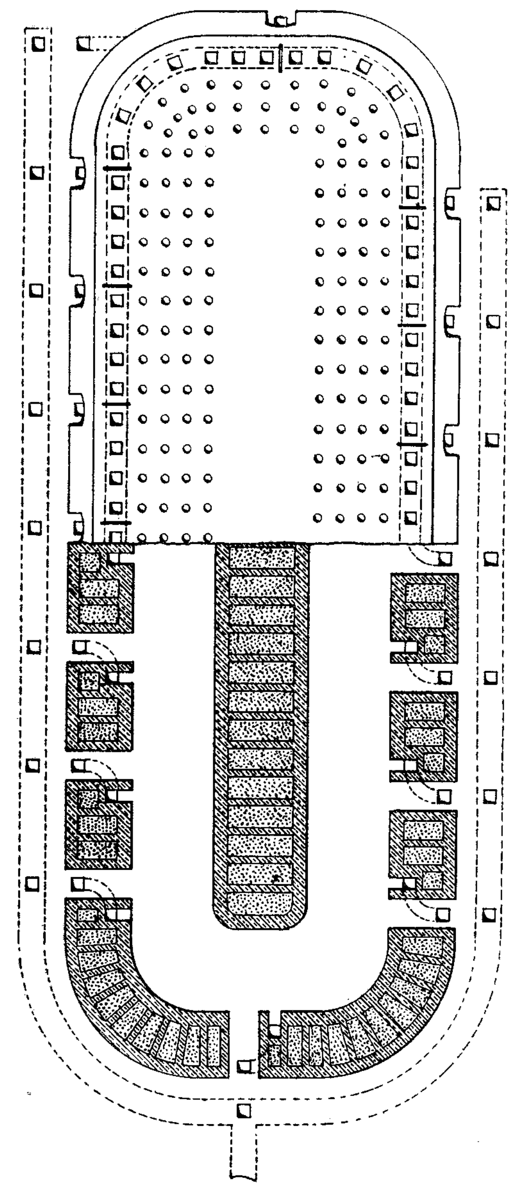


Figure 41.—Plan of modern Hoffman kiln. (After Lovejoy.)

The smoke gas flue is laid under ground around the outside of the kiln as indicated, and is connected by hood or goose-neck to the proper short flue which conducts the spent gases from the bottom of the kiln under the floor to an accessible point in front of one of the charging doors.

Sometimes, as when natural stack draft is used, the smoke flue is laid through the center wall and the draft controlled by dampers as shown by dotted lines in figure 40 and in figure 42. In this case the stack should be placed in the center within the kiln walls, as in this way its base is kept hot and a better draft obtained. Mechanical draft is always to be preferred for continuous kilns.

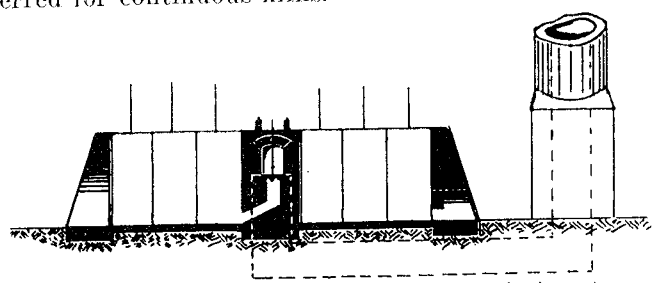


Figure 42.—Chinelewski kiln. (After Lovejoy.)

The firing is done entirely from the top of the kiln, through small fuel holes, equally spaced in the top of the tunnel about four feet apart. Directly under these fuel holes a fuel shaft is constructed (Fig. 43) in setting the brick, so that the fuel when fed into the firing hole rattles down through the setting.

In these kilns the ring tunnel is not cut up into chambers by cross walls or even dropped arches in the roof. It is usual to consider the distance from door to door, about 20 feet, as a chamber. Generally one or two chambers are set each day. At the end of each chamber some sort of draft regulator must be supplied. This is formed of light strips of wood supporting cheap heavy paper. The screen is made air tight by daubing the joints with clay. These paper partitions burn away as the fire advances and as each partition disappears the goose neck is set to take the gases from the far end of the new chamber.

The air passing through three or five cooling chambers is usually preheated to a temperature of 900°-1000°C by the heat absorbed from the cooling ware. It is then necessary to raise the temperature of this preheated air to that temperature required to burn the ware. This is done by burning a relatively small amount of fuel in the chamber which is on "fire." The gases passing from the fire chamber usually drop to 900°-1000C in passing through the first heating chamber, to 600°-700°C in the second, 300°-400°C in the third, 100°-200°C in the fourth, and 50°-125°C in the fifth.

While this kiln is economical in fuel when compared with the inter-

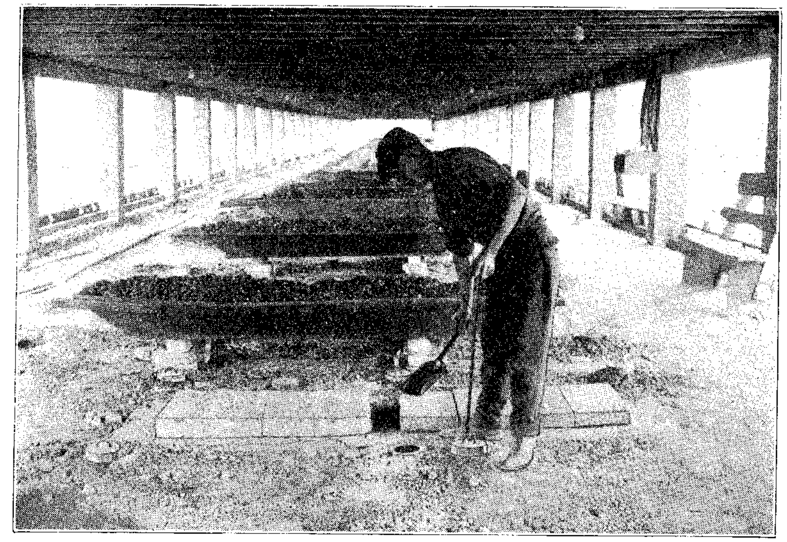


Plate XXVII, Figure 1.—Firing Haigh kiln through top firing holes.

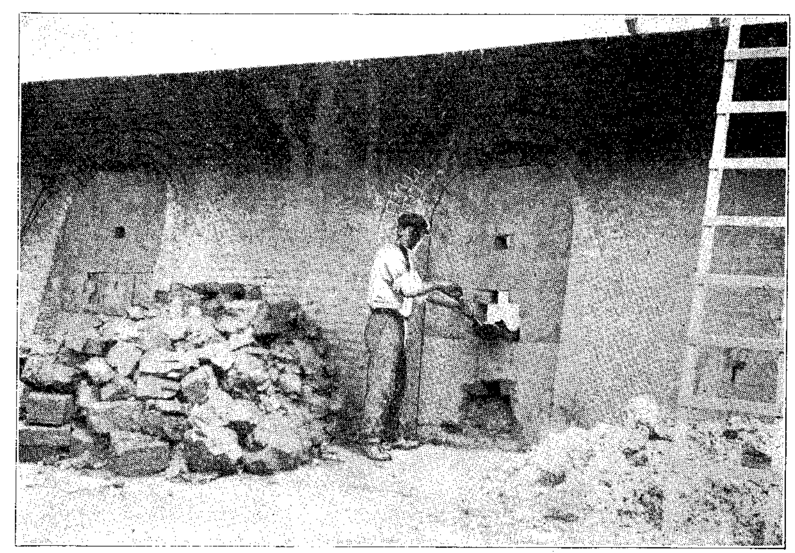


Plate XXVII, Figure 2.—Firing Haigh kiln through firing holes in wickets or doors.

(Cuts by Hadfield-Penfield Steel Co.)

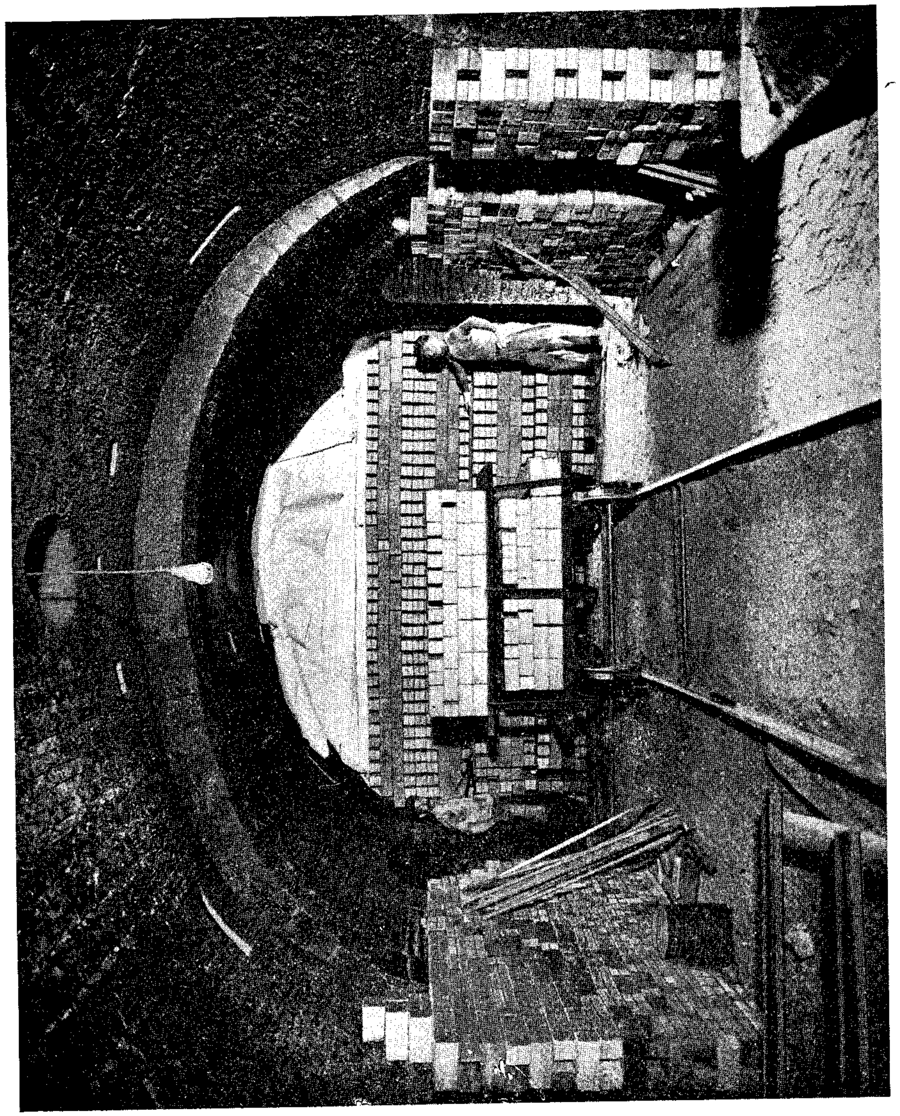


Plate XXVIII.—Interior of Haigh tunnel kiln, showing drop arches, paper separation between sections, and method of setting.
(From Hadfield-Penfield Steel Co.)

mittent kilns, the draft control is poor. The hot gases from the fire tend to rise and move horizontally until the exhaust flue is reached when they must pass down through the ware. In order to check this stratification the ware is set more compactly in the upper part of the kiln and more openly in the lower part. Although this method of setting tends to force the hot gases nearer the bottom during heating and so obtain better temperature distribution, it makes for very uneven cooling of the ware. During cooling the air is colder than the ware and tends to flow along the floor of the kiln unless heated or forced up by close setting in the lower part and open setting above. Generally even burning is more important than even cooling and the first method is employed.

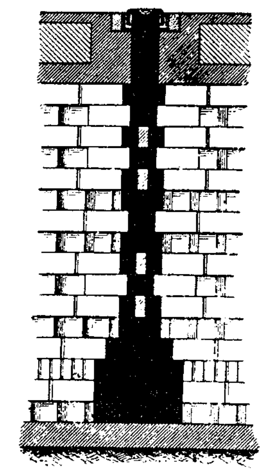


Figure 43.—Fuel shaft in setting of Hoffman klin.
(After A. B. Searle.)

Haigh Kiln. The Haigh kiln is very similar to the Hoffman except that the fuel may be fed into fire holes in the side instead of being dropped in from above (although sometimes both methods are used (Plate XXVII), and the chambers are set off by dropped arches which project down into the kiln a foot or more below the crown (Plate XXVIII). Both of these features tend for better temperature distribution, the side firing brings up the temperature of the bottom and the dropped arches force the hot gases down.

Chinelewski Kiln. The Chinelewski (Finnish) kiln shown in figure 42 is essentially a ring kiln such as the Hoffman without the crown, being a continuous horizontal draft, direct heat, open top kiln. The sections are closed by sheet iron plates lowered from the top into slots provided in the brick setting instead of the paper partition used in the crown kilns. The bricks are set to form longitudinal flues in the bottom and cross flues corresponding with the arched openings in the outside kiln wall. Vertical flues extend from the top of the longitudinal flues to the top of the setting. These flues are similar to those in the Hoffman setting and are used as stacks in the early stages of drying, when small fires are built in the small arch in the outside kiln wall, and as feed holes and fire ducts during burning. The setting is covered with two courses of platting and several inches of dirt, except over the vertical flues which are fitted with collars and caps.

Preliminary drying is done by small fires in the small arches in the outside walls connecting with the cross flues. The vertical flues give the necessary draft and control. When the bricks are dry and hot enough to stand the hot gases, the iron dampers are raised and the stack flue damper opened to pass the hot gases through the recently dried section. The small arches are closed and the independent fires extinguished.

Several years ago an attempt was made in New England to operate a *scoved kiln* as a *continuous regenerative* kiln on the same principle as just described. The only differences in construction were that the side walls were scoved after the kiln was set, and the smoke flue was placed underground instead of in the wall. The attempt showed much promise but was not repeated.*

Bock Kiln. The Bock kiln is similar to the Chinelewski kiln except that it is set below grade, has no arches in the side walls, and has many small draft openings immediately under the platting. This last change is decidedly for the worse as it simply aids the hot gases in their natural tendency to pass over the setting.

Klose Kiln. The Klose kiln is also of the open top type with the draft openings approximately midway between the platting and the floor. In this kiln the small independent drying fires are made unnecessary by an ingenious and far better method of water-smoking with hot air taken from the cooling sections. Figure 44 helps to make clear the construction

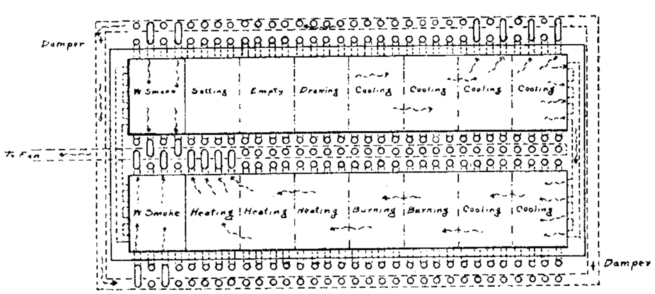


Figure 44.—Water smoking by advanced heat.
(After Lovejoy.)

and operation. The water-smoking sections are separated from the sections heating up and from the sections being set by paper shields pasted to the bricks. Some of the cooling sections are connected to the ad-

[1]Ellis Lovejoy, "Burning Clay Wares", p. 177.

vanced heat flue which completely surrounds the kiln, and can be shut off into two sections by dampers at each end. The hot air is drawn from the cooling sections through the advanced heat flue and the drying sections into the stack by the main stack fan.

The construction might be simplified by laying the advanced heat flue adjacent to the main stack flue, and providing inlets to the different sections at the top under the platting and on or under the floor. With this construction the hot air could be taken from the top of the cooling sections and supplied to the bottom of the drying sections which in turn would exhaust from the top into the stack flues, and the gases from the heating section could be taken off at the bottom. In this way the ideal of down draft heating and up-draft cooling could be approached.

This principle of advanced heat for drying, to prevent reducing, scumming, and swelling of the brick, was adapted to the Hoffman kiln as shown in figures 40 and 41, in which the advanced heat flues are in the upper outside kiln walls over the doors. Connections are made from the tops of the cooling sections by goosenecks to this flue and from the advanced heat flue to the drying sections through the similar feed holes. One or both of the flues can be placed in the center wall between the tunnels with a saving of about half the length of the flue.

Continuous Chamber or Compartment Kilns. The early types of ring or tunnel kilns were direct coal fired as has been described, and the burning fuel came in contact with the ware. This is objectionable in many cases, and means were devised to protect the high grade ware from the

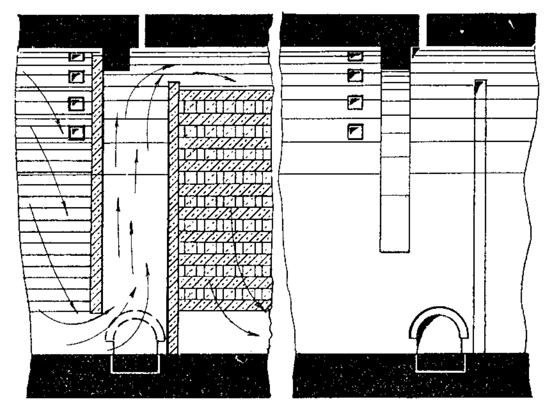


Figure 45.—Method of setting to convert ring or tunnel kiln to a compartment kiln.

fuel. This was done by building the vertical firing flues and horizontal floor flues of common bricks and filling the space between the flues with the high grade ware. This method was improved by setting a solid wall, except for openings corresponding to the horizontal floor flues, against the dropped arch. This green brick wall is virtually a division wall which remains closed, even if the bricks shrink so that the wall settles the depth of the dropped arch, making each section into a compartment. Back of each apron wall slots were placed in the kiln wall. A second solid green brick wall was set across the tunnel in these slots. This second wall was about 2 feet behind the first wall and was built solid from the floor, of bricks set herring-bone fashion, so that during fire-shrinkage the bricks would settle together and maintain a relatively tight wall. The extension of this wall into the side wall slots prevents any openings forming around the ends of the walls. This wall is not built up to the crown, and serves to divert the hot gases forced down to

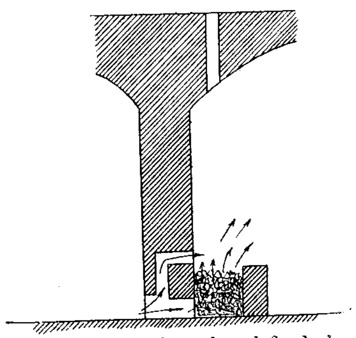


Figure 46.—Construction of coal fired chamber kiln. (After Lovejoy.)

the floor flues by the first wall up to the crown of the kiln. Figure 45 illustrates this conversion of a ring kiln to a compartment kiln. The firing may be done by producer gas admitted through a series of ports just behind the division wall, or by coal as shown in figure 46. This latter figure shows a permanent division wall with a number of ports in the base (as shown in cross section). The operation of the fire is similar to that of a producer and gives excellent combustion.

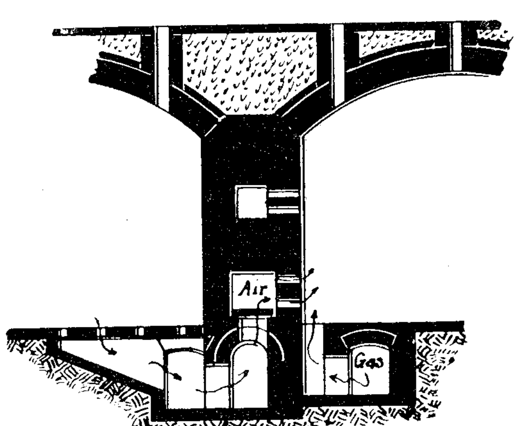


Figure 47.—Dunnachie (Mendheim) kiln. (After Lovejoy.)

This design really changes the direction of gas travel while passing through the ware, from horizontal to down draft. This feature is the one important advantage possessed by the continuous chamber kiln over the various types of tunnel kilns.

Mendheim Kiln. Mendheim in 1867 installed the first producer gas continuous chamber kiln. The original Mendheim kiln was up-draft in each compartment, the air and gas being admitted through cross flues under the floor of each compartment. This principle has been entirely superseded by the far more satisfactory down draft type. Figure 47 shows the system used in the Dunnachie kiln, which was introduced from Scotland in 1891 and later abandoned.

Figure 48 shows a more satisfactory type of construction for the Mendheim kiln. The advantages of the bag wall are brought out in

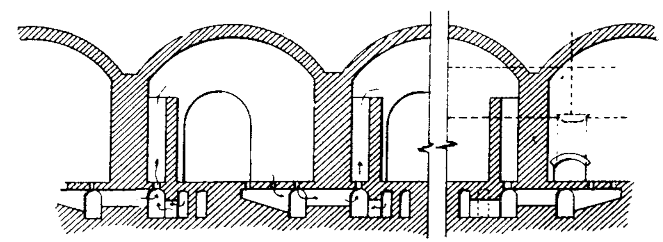


Figure 48.—Improved Mendheim kiln. (After Lovejoy).

figures 49 and 50. The cold air coming in from the left and passing through the cooling chambers tends to hug the floor as shown in figure 49, causing very rapid cooling of the bottom of the setting and very

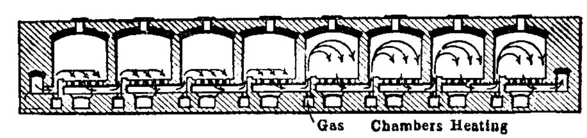


Figure 49.—Diagram showing how low bag walls give poor circulation. (After Williams.)

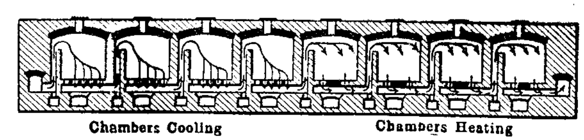
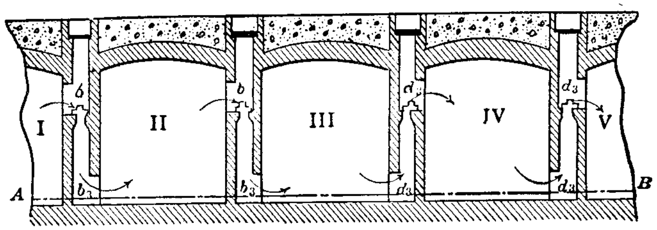


Figure 50.—Diagram showing how high bag walls give better circulation. (After Williams.)

little preheating of the air. This trouble may be partially overcome by the high bag walls but cooling ware in the down draft principle is as unsatisfactory as heating ware with an up-draft. The cold air will pass down through all the cold chimneys and not cool the hot areas when cooling on down draft, just as the hot gases pass up through all the hot chimneys not heating the cold ware on up draft heating. The high bag walls in figure 50 also aid in throwing the hot gases into the crown and improve their distribution in the burning and heating chambers. The *Adametzky kiln,* figures 51 and 52, is designed to overcome this



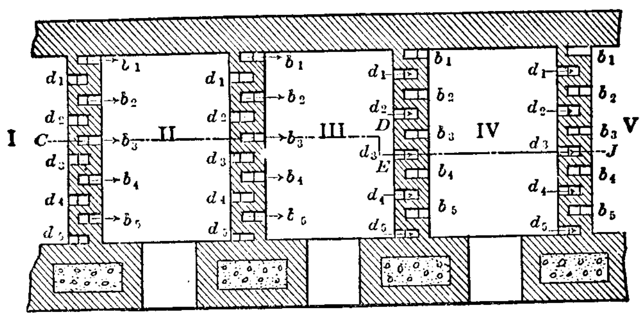


Figure 51, and Figure 52.—Adametzky kiln using up-draft cooling and down-draft heating. (After Williams.)

fundamental conflict of requirements in continuous chamber kilns. Chambers I and II are cooling on an up draft. Combustion takes place in III and heating is done on the down draft principle in IV and V. This change in gas travel is accomplished by the use of the alternate sets of flues connecting the chambers.

Youngren Kiln. The Youngren (English) kiln has been rather widely used in this country and is very satisfactory for burning face brick.* The kiln has been improved by various operators, as well as by the promoters, and at the present time there are more installations of Youngren kilns under several different names than any other compartment kiln. Figures 53 and 54 illustrate the 16 chamber Youngren kiln used for burning face brick by the Briggs Company at Grand Ledge. The producer gas is carried through a flue or pipe supported on the kiln wall and delivered to cross flues between the kiln arches by a goose neck. From the bottom of these cross flues are down-take flues in the division walls leading to ports into the bags at the base. Each of these individual gas flues is controlled by a valve as shown to the right of figure 54. The original Youngren kiln reduced the number of control valves by the branched construction shown in dotted lines on the left,

[1]W. D. Richardson, Trans. Am. Cer. Soc. 14, p. 778 (1912).

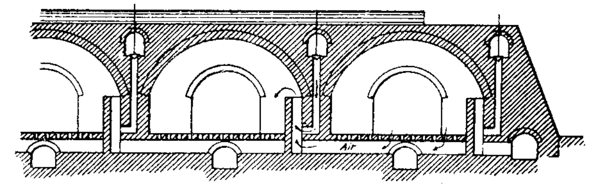


Figure 53.

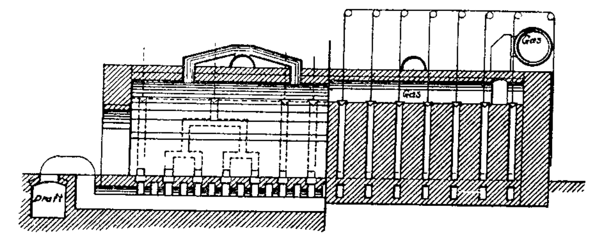


Figure 54.

Figure 53 and 54.—Vertical sections of Youngren (Raymond) kiln. (After Lovejoy.)

but the angles in these flues caused rapid carbon deposition, which was very difficult to remove. The hot air from the cooling compartments is drawn down through the ware, through the perforated floor, into parallel collecting flues leading forward through the division wall into the base of the bag below the gas port. As in practically all chamber kilns the draft or smoke flue is fed from a cross flue under the center of the floor of the chamber, which carries the spent gases from the heating chamber to the stack. The advanced heat flue runs on top of the kiln over the center of the chambers and is fed hot air by the inverted V hood shown on the left side of figure 54. A similar hood carries the hot air to the top of the chamber filled with green brick for the early part of the water smoking. The cold air is drawn off from the bottom of this chamber into the draft flue in the same manner as stack gases. This kiln demonstrates that water smoking may be accomplished in a perfectly satisfactory manner on the down draft principle if air is used as the heating medium. As water smoking is a heating operation, more uniform work can be done with down draft flow of the hot air. When stack gases are used, however, the sulphur dioxide reducing gases, soot, and dust particles in the gas are absorbed in the water condensed on the cold brick in the bottom of the setting, causing scumming, swelling, and spotting of the ware.

This is the only continuous chamber kiln operated in the State. It is producing an excellent hard burned face brick known locally as "Old Rose Mission" brick. The kiln is fired at about cone 3, carrying one chamber each, water-smoking, oxidizing, vitrifying, under fire, and cooling or preheating the air. Each chamber has a capacity of about 65,000 brick giving a daily capacity of about 43,000 brick as the fire is moved about every 30 or 35 hours, the burning cycle being about 120 or 125 hours.

Mark A. Taylor[1] describes a successful installation of *Youngren kilns* burning oil fuel. The oil is atomized by air and introduced into the combustion chamber by a burner under the crown.

Other chamber kilns, such as the Underwood, Richardson, and Legg are of the same general type having special features in location of flues and means of control.

A weakness of all compartment kilns is the tendency of the division walls to lean in the direction of the draft, throwing the arch as shown in figure 55. If this continues the kiln has to be rebuilt after a few years'

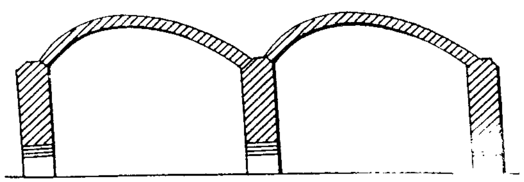


Figure 55.—Leaning of division walls of compartment kilns. (After Lovejoy.)

use, a rather expensive matter. The life of the kiln depends upon the thickness and solidity of the division walls, their height, the quality of material and workmanship put into the construction, the use of the crown and temperatures attained. If the firing can be reversed annually or semi-annually the slight displacement might be corrected during the reversed firing.

The modern ring and chamber kilns have two tunnels connected by underground flues, or built in the form of a U, and wickets on opposite sides of each section or chamber, allowing the green ware to be handled in the space between the tunnels, while the burned ware is discharged through the outside walls and loaded in cars on a depressed track.

A compartment kiln fired with producer gas will usually burn the same amount of ware on less than one-half as much coal as direct fired intermittent down draft kilns. If the crowns are built into iron frames and made portable by a crane, the chamber kiln offers the advantages of an open top kiln in ease of mechanical loading. The small sections of a portable crown are also easily repaired.

Heat balances on continuous compartment kilns show from about 20 to over 40 per cent of the heating value of the coal actually used to heat the clay ware.[2] The higher figure is probably seldom attained or exceeded.

The compartment kiln offers a wide range of practical utility in burning brick and tile as well as the higher grade products at a saving in fuel of about 40 to 70 per cent over the intermittent down draft kiln.[3]

[1]J. Am. Cer. Soc. 6, p. 1057 (1923).
[2]C. Treischel and Robertson, J. Am. Cer. Soc. 1, p. 322 (1918).
R. K. Hirsch, J. Am. Cer. Soc. 1, p. 567 (1918).
[3]W. D. Richardson, J. Am. Cer. Soc. V, p. 255 (1922).

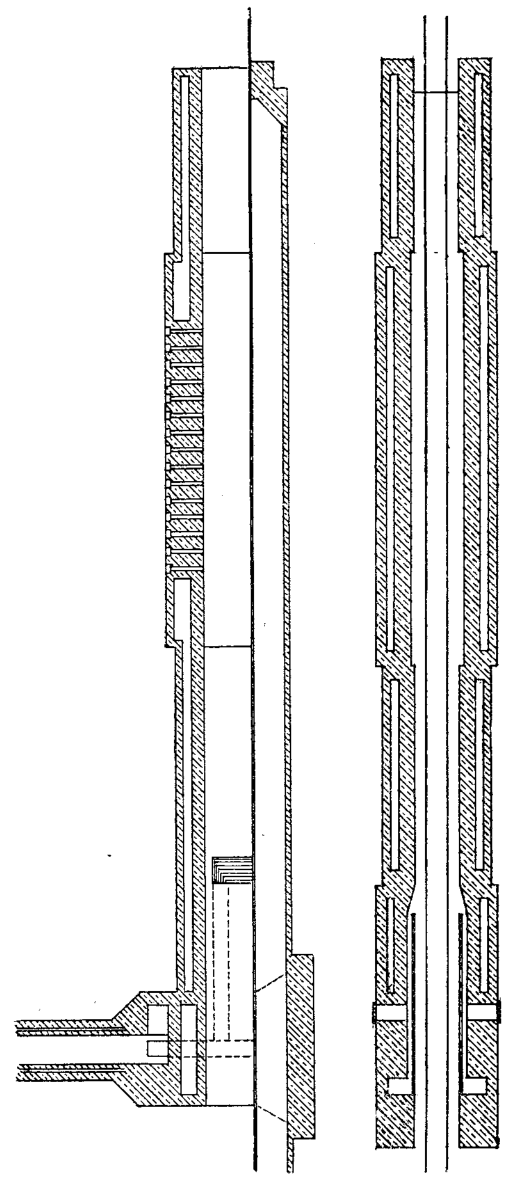


Figure 56-a. b.—Vertical and horizontal sections of Bock kiln—car-tunnel type. (After Lovejoy.)

Car Tunnel Kilns. In Car tunnel kilns the different steps in the burning process always occur in the same part of the tunnel, which has a sationary heat zone through which the cars carrying the ware are pushed in a continuous train by a hydraulic cylinder or mechanical device at the entrance end.

The regenerative principle is fully applied as in the case of the ring or chamber kilns. The fuel is always supplied and burned at the same place in the kiln, making the gas flue and annoying goose necks unnecessary. The hot zone is fixed and constant, relieving the kiln of the strains caused by alternate heating and cooling. Only that part of the kiln subject to the high temperatures need be built of highly refractory materials, and this zone may be carefully insulated, reducing loss of heat through the kiln walls. A marked saving in handling the ware is made by using a car on which the ware is loaded to carry the ware entirely through the burning process and, if desired, the drying also; thus eliminating the setting and drawing of ware in the kiln and even in the drier.

Direct Heat Horizontal Draft Kilns.

Probably the first tunnel kiln was built in 1751 at Vincennes, France,* followed by another in 1765[2] and still another in 1840 by Yordt for burning brick in Denmark.

The early *Pechine kiln* had a fire at one end and seemed to be developed from an end fired periodic kiln. Bonie moved the fires to the center of the tunnel. After the development of the Hoffman ring kiln *Bock* built a car tunnel kiln by putting cars in a small Hoffman kiln. The cars are covered with a refractory floor which supports the ware. An apron attached to the car floor on top of the car frame runs in a sand filled trough cutting off the metal car and under tunnel from the firing tunnel. The air supply enters under the cars from the stack end, flows the entire length of the tunnel, keeping the cars cool, and enters the firing tunnel at the opposite end, cooling the hot brick. This preheated air is then used to burn the coal fired through feed holes, as in the Hoffman kiln, and finally passes up the stack. In order to prevent scumming of the green ware Bock used a metal diaphragm to form the inner side walls at the receiving end where the gases enter the stack. The diaphragm ends in the firing tunnel at the point where the waste gases are assumed to become saturated, and here removes the gases from contact with the ware, the flues being on one side and the ware on the other side of the diaphragm. In this way the heat in the gases is absorbed by the iron plate and passes on the green ware without so much danger of spoiling the ware as if the saturated gases and bricks come into direct contact. About 60 Bock kilns have been constructed, most of which were failures, due to difficulty in water smoking and oxidation.

[1]Brick and Clay Record 66, p. 22 (Jan. 6, 1925).

[2]Bollincke, Brick 2, No. 6, p. 395.

The second *Siemens-Hesse kiln* is essentially a gas fired Bock kiln. This kiln is simple in construction and may be classed as continuous, direct heat, horizontal draft and closed top. The same principles are applied in a number of tunnel kilns of improved construction.

The *Zwermann kiln** built by the Russell Eng. Co. used by the Kalamazoo Sanitary Manufacturing Company for burning sanitary earthenware is shown in figure 57. The kiln is 360 feet long, 6 feet 4 inches wide, and 6 feet 6 inches high from the floor of the trucks to the arch. It will hold 46 trucks 7 feet 7½ inches long, 19 trucks in the preheating zone, 8 trucks in the firing zone, 18 trucks in the cooling zone, and one in the vestibule. The loaded trucks are introduced at two hour intervals, the cycle taking 92 hours.

The cooling zone is supplied with a muffle flue over the arch and 3 flues in each side wall. Air is drawn in through the arch flue and the two lower side flues by the exhauster as shown in sections K-K, J-J, H-H.

These flues extend through the last three-fourths of the cooling zone only, and supply air at 250°F for drying the ware. The upper flue in each side wall runs through the entire cooling zone and then down under the oil burners below the floor level of the cars throughout the burning zone. Air is blown into this recuperator flue by the blower at the discharging end supplying forced draft for the combustion. Firing is done by 5 oil burners, staggered 3 on one side and 2 on the other. The oil, atomized with compressed air mixes with the preheated air and passes directly into a combustion chamber, on top of the center of the car floors, as shown on the cars in the tunnel. The hot gases then pass up around the saggers containing the ware and horizontally toward the charging end where they are drawn off from the floor of the kiln as shown in section A-A. This method of firing results in an up-draft in the burning zone tending to burn the lower layers faster than the upper layers, and a horizontal draft through the heating zone where the hot gases pass along the top tending to heat the upper layers faster than the lower. These two factors can be made to compensate in this kiln so that the burning effect is about even at all positions in the cars. The kilns at Kalamazoo burn the ware to cone 9 and 10 with a difference of less than one cone between the top and bottom when properly fired. Two small auxiliary stacks about 8 inches in diameter pass through the crown in the high heat zone to draw off reducing gases which may form eddies in the burning zone.

As all the air and fuel is under direct positive control, none of it drawn in through the ware, the kiln may be operated under either oxidizing or reducing conditions.

In firing large pieces and small pieces of ware simultaneously, the small pieces must be evenly distributed with the large ones, or the burn-

*J. Am. Cer. Soc. I, p. 262 (1918); V, p. 611 (1922).

ing is uneven; the large pieces having a high heat capacity absorb a much larger amount of heat for a given temperature rise than the small ... the small pieces will be over burned if

s.
e
s
r
te
ct
ed
nt
at
ng
h.
F.
lic
rs,
ee
lel
hot
rch,

giving underburned ware in the lower tiers. In the Zwermann kiln described above this tendency has been compensated by making the burning zone up-draft. Grum-Grzhimailo,* the Russian engineer, recommends

*Flow of Gases in Furnaces, Trans. by Williams, Wiley (1923.)

The second *Siemens-Hesse kiln* is essentially a gas fired Bock kiln. This kiln is simple in construction and may be classed as continuous,

a

n
w
a
h
8
v
c

ir
k

oı
ea
th
zo
ch
by
at
di
as
th
en
tio
zo
a
al
Th
bu
Ka
on
au
in
in

in

reducing conditions.

In firing large pieces and small pieces of ware simultaneously, the small pieces must be evenly distributed with the large ones, or the burn-

*J. Am. Cer. Soc. I, p. 262 (1918); V, p. 611 (1922).

ing is uneven; the large pieces having a high heat capacity absorb a much larger amount of heat for a given temperature rise than the small pieces, and are under-burned, or the small pieces will be over burned if the firing is regulated according to the demands of the large pieces. This is another case of the rate of attaining equilibrium, if the ware were fired for a very long time the heat would soak equally into all pieces regardless of size, but when under fire for only 16 hours the smaller pieces soak up relatively more heat than the large pieces.

At the Kalamazoo plant the ware is fired in saggers to protect the white ware from the flames and flue gases. These saggers also protect the ware from the flue gases during water smoking. The kiln is reported to be easy to control and has proved very satisfactory at this plant where two are in operation, one 285 feet long, operating as glost kiln at cone 6, and the other 360 feet as described. Temperatures of the firing zone are recorded by eight thermocouples inserted through the arch. The stack gases leave at about 130°F and the ware at about 350°F. These kilns operate on oil fuel at about the same fuel cost as periodic kilns formerly fired with coal. The kilns have had no refractory repairs, and so far as is known have been operated continuously except for three shut downs caused by the factory burning down.

A later design of the Zwermann kiln (Figs. 58, 59) has two parallel tunnels instead of the single tunnel used at Kalamazoo.

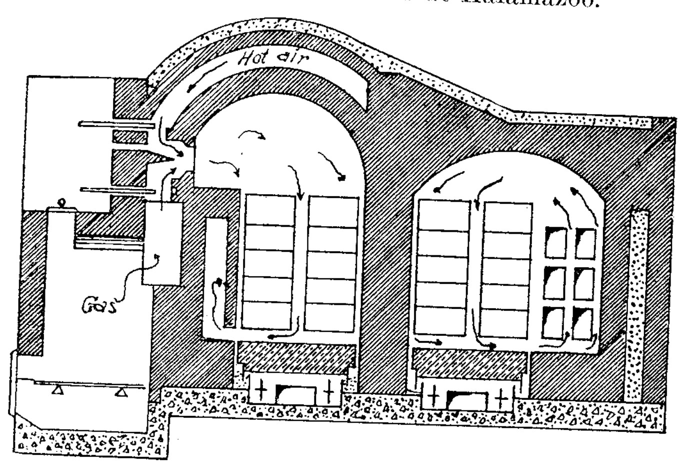


Figure 58.—Cross section of double tunnel Zwermann kiln. (After Lovejoy.)

All horizontal draft kilns work under a serious disadvantage; the hot gases tend to pass over the ware along the kiln just under the arch, giving underburned ware in the lower tiers. In the Zwermann kiln described above this tendency has been compensated by making the burning zone up-draft. Grum-Grzhimailo,* the Russian engineer, recommends

*Flow of Gases in Furnaces, Trans. by Williams, Wiley (1923.)

forming the tunnel on the arc of a vertical circle, raising the central burning zone higher than the ends, so that in cooling the product the cold air will pass upwards as well as horizontally, and in heating the green ware the products of combustion will flow downwards as well as horizontally. This tunnel embodying the correct principles of up-draft cooling and down-draft heating, has much to recommend it. The same idea has been applied successfully in the *Arminoff furnace*[1] for the continuous carbonization of wood in Sweden.

The *Faugeron kiln* developed about 25 years ago is divided into sections by drop arches or step downs in the tunnel crown. The walls are hollow on each side of the step downs to points midway between them, and the inner walls are perforated at the level of the car floor to connect with the flues in the walls as shown in figure 60. The ware on the car is set to fit the tunnel under the drop arches very closely so that in passing these points the free area is so restricted that part of the air or gas will be forced down through the ports in the floor to pass the drop arch. This construction tends to make for more even distribution of the hot gases. The combustion chambers are so arranged to supply the hot gases to the bottom of the setting, in that way approximating up-draft conditions. The fire boxes are used as semi-producer furnaces, taking the primary air from the wall flues, under the grate, and the secondary air above the grates as indicated in the cross section. A kiln of this type 197 feet long used by the General Electric Co., Schenectady, N. Y., uses 650 pounds of coal per 1,000 9 inch brick, with the gases leaving at 200°C.[2]

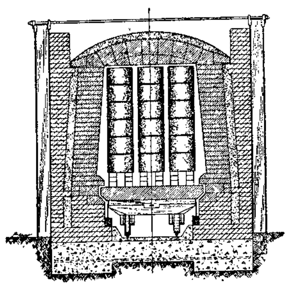


Fig. 61.—Section of Harrop kiln. (From Brick and Clay Record.)

The Harrop kilns[3] used by the Mount Clemens Pottery[4] aim to force the hot gases through the lower part of the ware by setting baffle blocks

[1]Rev. de la Societe russe de Metallurgie No. 1, pp. 48-64 (1912) cf. also Rev. de Metallurgie Dec. 1913, p. 678.
[2]L. E. Barringer, Trans. Am. Cer. Soc. 18, p. 106 (1916).
[3]E. Lovejoy, Clayworker 78, p. 448 (1922).
[4]J. Am. Cer. Soc. 4, p. 673 (1921); 5, p. 614 (1922).

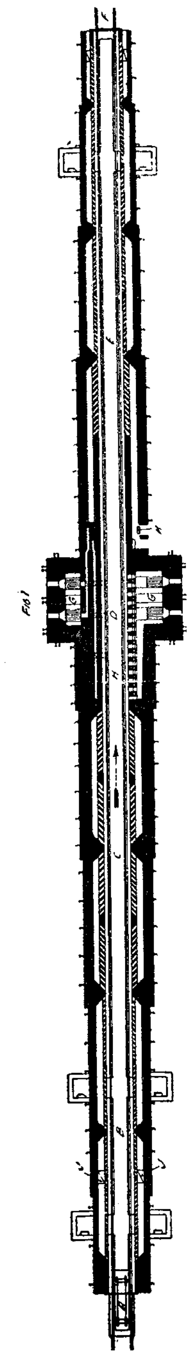


Figure 60.—Faugern (Didier-March) kiln. (From Brick and Clay Record.)

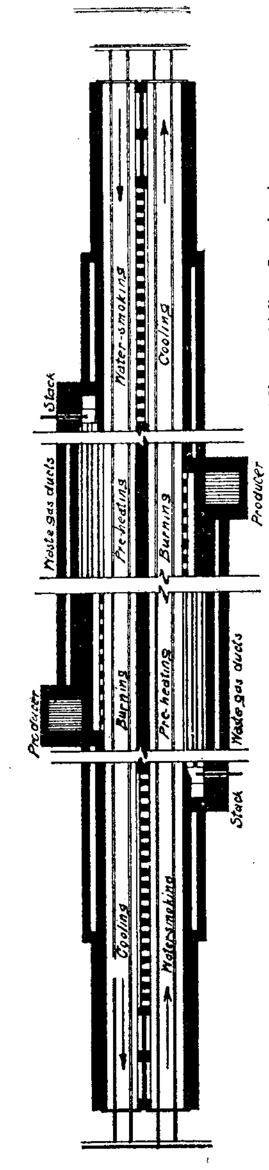


Figure 59.—Longitudinal sections of double tunnel Zwermann kilns. (After Lovejoy.)

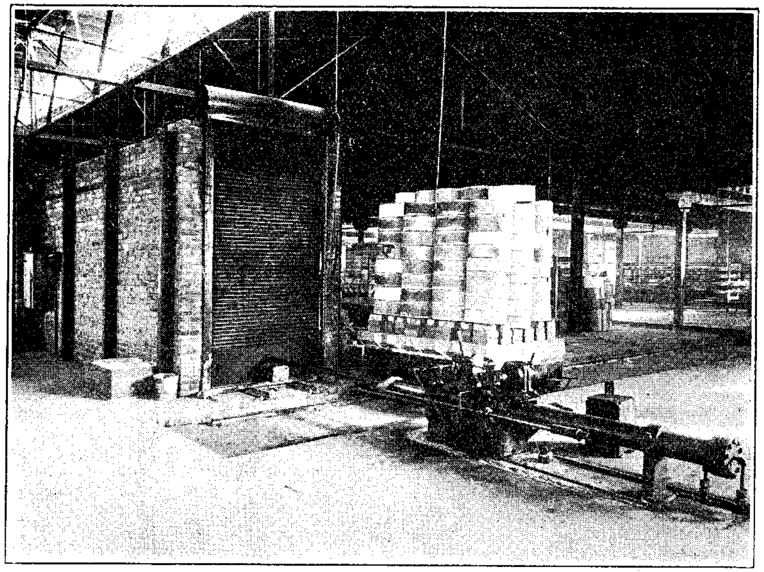


Plate XXIX. Figure 1.—Ware entering Harrop kiln, Mt. Clemens. (From Jour. Am. Cer. Soc. 4 p. 674,—1921.)

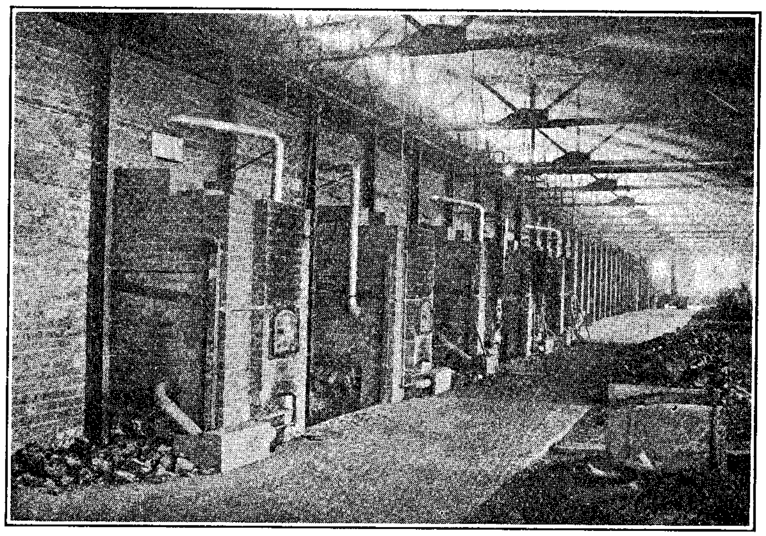


Plate XXIX, Figure 2.—Furnaces in Harrop kiln, Mt. Clemens. (From Jour. Am. Cer. Soc. 4 p. 674,—1921.)

on top of the ware or building baffles into the crown, in much the same way as used in the Faugeron kiln. The construction is simplified in omitting the horizontal flues connecting the lower part of the tunnel around the baffles, and instead, batterying the sidewalls of the tunnel as shown in figure 61 to leave very little clearance around the top of the ware and relatively large clearances around the lower sides and bottom of the setting. In this way the flow of hot gas along the top is impeded and some of it takes the less resistant route through the lower part. These kilns are used in burning table ware, one 323 feet 6 inches long firing bisque to cone 10, and one 273 feet 6 inches long as a glost kiln operating at cone 6. The building housing the two kilns placed end to end is 825 feet long.

The ware is set up on fire brick stilts (Plate XXIX) to allow easy passage of the hot gas below the ware. Five furnaces are used on each side of the bisque kiln. Four similar furnaces are used on each side of the glost kiln. The grates consist of a cast iron plate with a hollow box below connecting to two long tuyeres located on top of the plate running transversely with respect to the furnace. The walls surrounding the furnace are air cooled to prevent clinkers sticking to the masonry, by the air used for primary combustion of the fuel on the grate plates. This air with some steam enters the fuel bed through the tuyeres. Kentucky bituminous coal is fired by the coking method. Secondary air, preheated to about 400°F by passing over the crown of the cooling end of the kiln and then over the furnace arch, is admitted through three inlets on each side of the charging door.

It requires 8,100 pounds pressure to push a train of 44 loaded cars in the bisque kiln and 4,860 pounds for the 37 loaded cars in the glost kiln. The bisque tunnel kiln requires 1.22 pounds of coal per dozen ware against 7.8 pounds used by the 13 old 16½ foot diameter periodic down-draft kilns or a saving of about 85 per cent. The glost kiln requires 1.8 pounds per dozen ware saving about 82 per cent of the fuel required by eleven 16½ foot intermittent kilns. The bisque kiln was built at a cost of about $60,000 in 1920, when prices were high.

These kilns are reported to be very satisfactory and have required no repairs. Other kilns of the same construction are used for low tension electric porcelain cone 12 by the General Porcelain Company, Parkersburg, W. Va.,[1] for sanitary ware[2] cone 10 and other high grade products. The Champion Porcelain Co., Detroit, is using an oil fired Harrop kiln to fire spark plug porcelains to a temperature of cone 20. Considerable difficulty was experienced in adapting the kiln to meet the exacting demands of burning spark plug cores. This has been done and the kiln is now giving satisfactory service.

[1]Cramer, J. Am. Cer. Soc. 5, p. 492 (1922).
[2]Gavin & Hartford, J. Am. Cer. Soc. 6, p. 1214 (1923).

The *A. C. Spark Plug Company Kiln,* Flint, Michigan, (Plate XXX) is a small tunnel kiln used for burning their spark plug porcelains (single fire glazed) in 1919.[3] The kiln is 60 feet long with 15 feet additional sheet metal wind tunnel, 2 feet 8 inches wide and 3 feet high to further cool the ware. The kiln is direct fired with city gas of about 550 B.t.u. heating value. Five burners on each side operating on the surface combustion principle direct the flame upon the arch giving very rapid and complete combustion. The cars are four feet long and are moved continuously by chain pusher through the kiln at the rate of one inch per minute, burning the porcelain to cone 18 in 12 hours, against 4 to 5 days with the periodic kilns. The kiln is divided into 3 zones, each 20 feet long. The burning zone being separated by drop arches from the heating and cooling zones. The cooling zone is cooled by an air flue in the arch, water coils directly over the ware, and direct air circulation through the 15 foot wind tunnel which is separated from the kiln proper by a metal flap to prevent the air blowing into the kiln. The stack gases diluted with air leave at 100°C.

The spark plug porcelains are laid in a single horizontal tier on 1½ inch fire clay tray set up by blocks above the top of the car. The ware above the trays is burned to cone 16 and tile placed below the trays is burned to cone 3 in the same travel through the kiln. This shows the vertical heat distribution to be very poor. This otherwise serious disadvantage is overcome by stacking the ware in one horizontal tier. The kiln is rugged, simple and economical. The cost of firing with city gas at 87 cents a thousand cubic feet is about the same as for periodic kilns using coal.

Another kiln of the same design was built later at the same plant. This kiln, 87 feet long, 5 feet 2 inches wide, and 3 feet high has about twice the capacity of the small kiln and uses only one and one-third times as much fuel.

Direct Heat Down Draft Kilns.

The tunnel kilns described above use use a horizontal flow of the hot gasses as they pass through the clay ware, and depend upon the different means described to compensate for the very poor heat distribution in a simple horizontal draft kiln. The *Drayton tunnel kiln* (Fig. 62) uses drop arches, and division walls carried on short cars, to make the tunnel in reality a series of down draft compartments. The kiln may be considered a continuous down draft direct heat compartment car tunnel kiln with advanced heating flue. The Drayton kiln is divided into sections holding about 3 cars each. Three cars are charged as a unit into the kiln at one time together with a short car carrying a division wall. The division wall has a vertical flue connecting

[3]S. J. McDowell and P. D. Hesler, J. Am. Cer. Soc., pp. 267, 610 (1922).

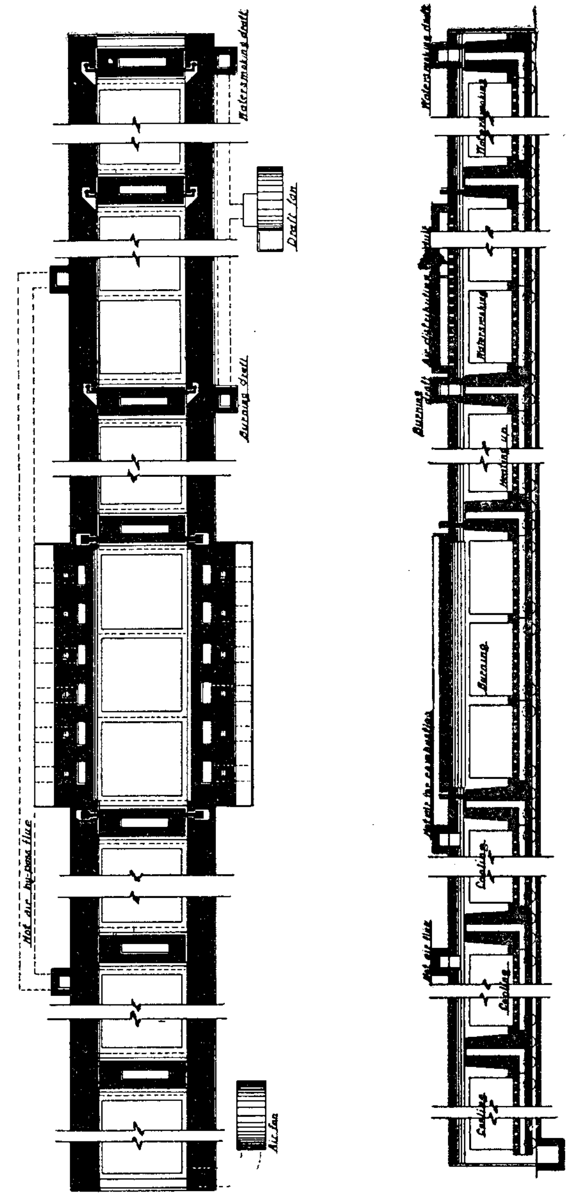


Figure 62.—Sections of Drayton down-draft tunnel kiln. (After Lovejoy.)

with the horizontal flues in the floors of the cars. In the main walls of the tunnel throughout the burning and heating zones, sliding vertical dampers are built corresponding to the positions occupied by the division walls on the short cars, and through a slot in the crown over each division wall is a horizontal fire clay damper. When a unit charge of three cars, more or less, followed by a division wall, is pushed into the kiln, the division walls come opposite the damper slots and under the fire clay damper. Following each charge the side dampers are shoved in and the top dampers lowered, making a series of down draft chambers through the burning, heating, and water smoking zones. In the cooling zone up to the combustion zone there are no dampers.

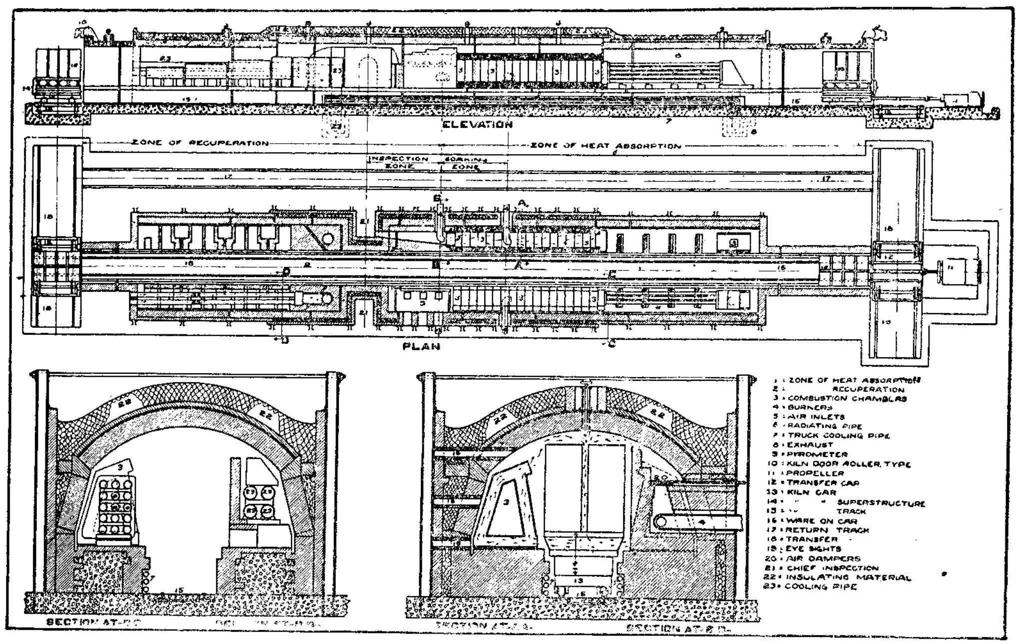


Figure 63.—Two cross-sections and drawings of Dressler muffler type kiln. (From Brick and Clay Record.)

In operation a fan forces air into the cooling zone, through the car floors, and under the cars. The air under the cars passes forward and is delivered under the furnace grates. This keeps the car bottoms cool and serves to preheat the primary air. The air forced in through the car floors passes up through the ware cooling the ware on the correct up-draft principle. Some of the air heated in this way is by-passed from the top of the tunnel to a hot air distributing flue over the second water smoking chamber, thus embodying the principle of advanced heat water smoking by hot air. The remainder of the air heated in passing upward through the hot ware is taken off by an overhead flue and delivered

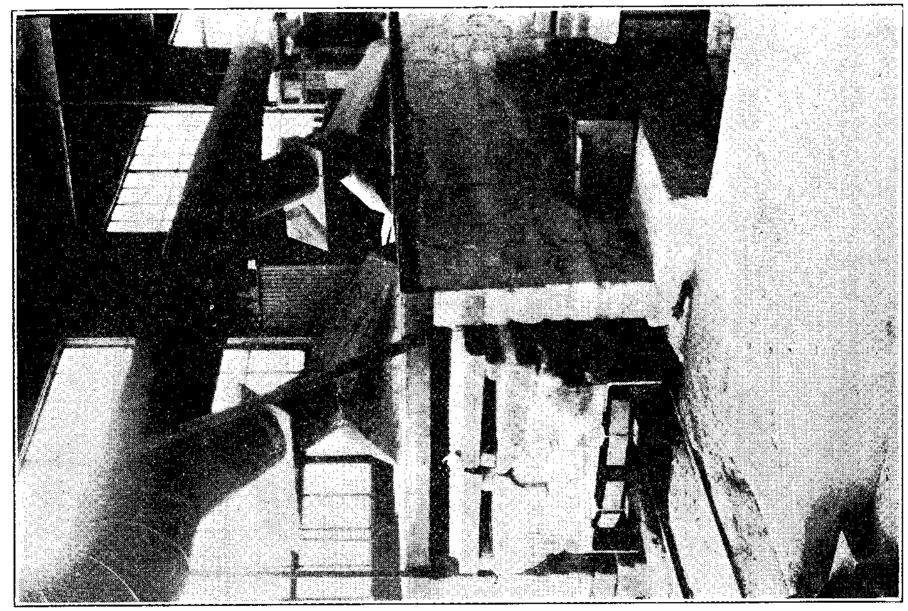


Plate XXX, Figure 2.—Discharge end of A. C. kiln at Flint. A. Cer. Soc. J. 5 "1922".)

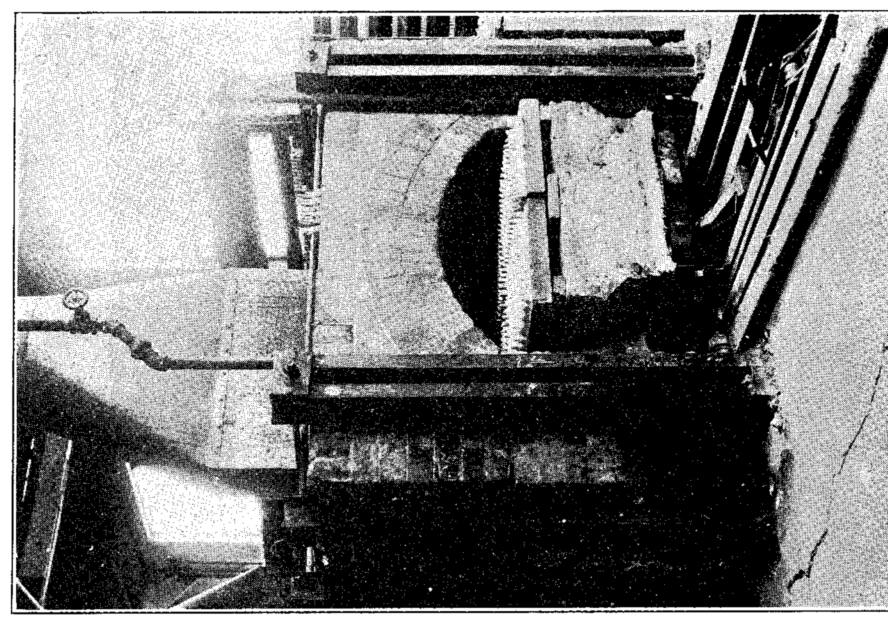


Plate XXX, Figure 1.—Spark plug cars entering A. C. kiln at Flint. (From Jour. Am. Cer. Soc. 5 p. 270,—1922.)

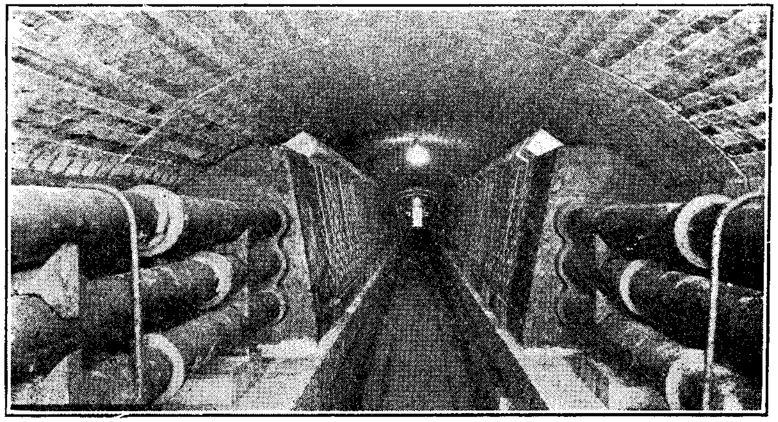


Plate XXXI, Figure 1.—Cooling pipes in Dressler kiln. (From Fuels and Furnaces 2 p. 36,—1924.)

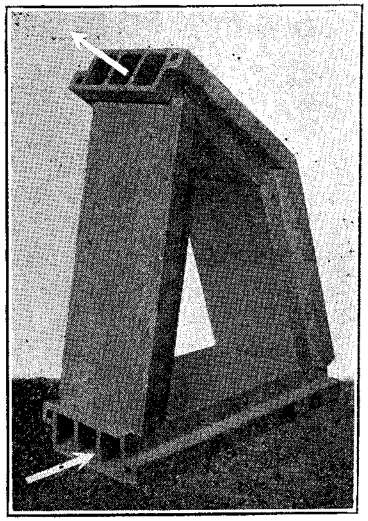


Plate XXXI, Figure 2.—Combustion flue tile, Dressler kiln.

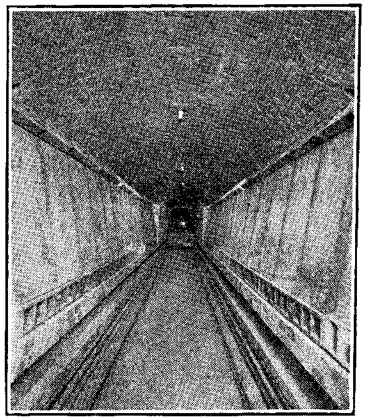


Plate XXXI, Figure 3.—Combustion flues, Dressler kiln. (From Fuels & Furnaces 3 p. 128,—1924.)

through dampers to down takes supplying the secondary air for combustion.

The combustion gases pass up into the crown behind the bag walls and thence down through the ware into the floor flues in the cars, up through the division wall flues into the heating compartments, and finally are drawn off by the draft fan through a flue connecting with division wall flue at the end of the heating section.

This kiln offers advantages of up-draft cooling, down-draft burning, and heating with separate water-smoking by hot air, but is rather cumbersome in operation.

Muffle Kilns. The *Dressler Tunnel Oven** (Fig. 63) patented in 1910 in England, is a continuous muffle kiln with down draft heating and up-draft cooling of the ware, but horizontal draft of the combustion gases inside the muffle. The kiln consists of two rather distinct parts. The cooling zone carries cold air pipes inside the tunnel, (Plate XXXI), cut off from the hot ware by a wall (Fig. 63, section DD) to prevent too rapid cooling of the ware. Cold air drawn through these pipes by an exhaust fan is heated in cooling the kiln gases and used to dry the green ware or for some other purpose outside the kiln. Air is also allowed to pass through this part of the tunnel, entering at the discharge end and pursuing a spiral path through the ware due to the combined horizontal draft and up draft through the hot ware and down draft around the cold pipes. The burning and heating zones constitute the second part of the kiln.

The air for combustion is drawn through the cooling zone and into the horizontal combustion flue through ports at the beginning of the combustion zone. The gas is delivered through a cross duct under the tunnel and rises through vertical flues into the combustion chambers either behind or ahead of the air as the designer prefers. These combustion chambers form continuous flues built of very thin fire clay, or preferably carborundum, on each side of the tunnel in the combustion zone. The combustion flue runs lengthwise of the tunnel and is completely surrounded by transverse flues for air circulation and heat connection from the muffled combustion chamber or flues to the ware loaded on cars (Plate XXXI). The hollow blocks constituting the combustion flues also contain the walls of the transverse flues, so that the hot wall of the combustion flue is supported and prevented from sagging by the relatively cooler outer walls of the transverse flues. It was found that the heat transfer from the walls of the combustion flue to the air in the kiln was greatly increased by the addition of these transverse flues due to the greater velocity of the air in the restraining flues. so that the walls of the flues are heated to a temperature only slightly above the ware. The combustion flues are built up of a series of sections laid side by side,

*Trans. Am. Cer. Soc. XVII, p. 527 (1915).
C. J. Kirk, ibid XVIII, p. 535 (1916).

each section composed of four refractory pieces resembling thin wall hollow tile and combined to form a stable structure with continuous passages between the top and bottom members (Plate XXXI). The heat liberated by the combustion on the inside of the chamber causes the flues in the back and front to act as chimneys, the kiln gases being drawn in at the bottom and discharged at the top.

The products of combustion become rapidly cooled and through the latter half of the heating zone are carried in cast iron pipes instead of the more expensive refractory material which is not needed at lower temperature.

The Champion Porcelain Company, Detroit, uses a Dressler kiln for burning their spark plug porcelains, approximating sillimanite (Al_2O_3 SiO_2) in composition, to cone 20 in saggers. This is the highest temperature used in any tunnel kiln, even those direct fired. The overall length of the kiln is 303 feet 6 inches. The kiln holds 48 cars, 6 feet long by 32 inches wide upon which are loaded eight bungs or carborundum saggers containing the spark plug cores (Plate XXXII). One car is charged into the kiln every hour, making a 48 hour cycle. The heating zone is about 180 feet long and the cooling zone about 120 feet. City gas of about 500-550 B.t.u. heating value was formerly used but has recently been superseded by oil. As the gas varied rapidly in composition and density, some means had to be provided to automatically control the gas valve depending upon the flame length and heating value of the gas. This control was very satisfactorily worked out and combined with an automatic control of the kiln temperature.[1]

During the first six months of operation[2] this kiln was down twice for repairs to the refractory muffle but this trouble has been overcome since that time and the kiln has given continuous satisfactory service.

In order to obtain the reducing atmosphere necessary just before the maturing point of the porcelain, auxiliary burners discharging into the kiln atmosphere at the level of the car platform are provided. These burners are also controlled automatically but in a somewhat different manner from the main burners. The ware is preheated by a blast of hot air before being charged into the kiln to aid in attaining the desired temperature.

The Dressler Muffle Kiln has been adapted to most high grade products including glass house refractories[3] and semi-porcelain table ware.[4]

Another muffle kiln of simpler construction is the *decoration kiln of*[5] the *Mt. Clemens Pottery Company* constructed in April 1922. The kiln has a carborundum muffle but instead of employing the surrounding

[1]T. R. Harrison, J. Am. Cer. Soc. 6, p. 1128 (1923).
P. Dressler, Fuels and Furnaces 2, pp. 33, 125, 249 (1924).
[2]J. Am. Cer. Soc. 5, p. 609 (1922).
[3]C. J. Hudson, J. Am. Cer. Soc. 4, p. 738 (1921).
[4]Sproat and Allbright, J. Am. Cer. Soc. 3, p. 460 (1920).
[5]J. T. Jans, T. Am. Cer. Soc. VII, p. 626 (1924).

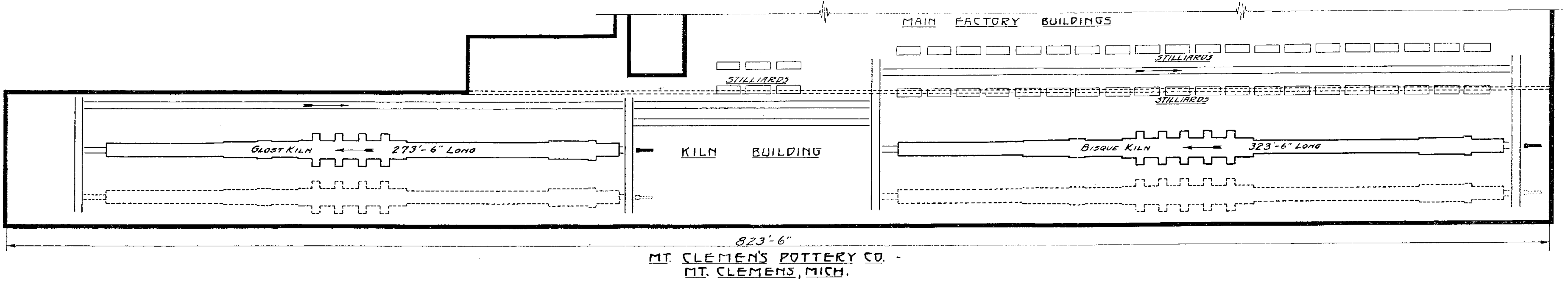


Figure 66.—Plant layout, Mt. Clemens (Amer. Cer. Soc.)

each section composed of four refractory pieces resembling thin wall hollow tile and combined to form a stable structure with continuous passages between the top and bottom members (Plate XXXI). The heat liberated by the combustion on the inside of the chamber causes the flues in the back and front to act as chimneys, the kiln gases being

dra

T

latt

the

tem

T

burn

SiO

atur

leng

long

run

car

heat

City

rece

and

gas

This

auto

D

for

since

In

mat

kiln

burn

man

hot

temp

Th

inclu

Ar

the

has

[1]T. R. Harrison, J. Am. Cer. Soc. 6, p. 1128 (1923).
P. Dressler, Fuels and Furnaces 2, pp. 33, 125, 249 (1924).
[2]J. Am. Cer. Soc. 5, p. 609 (1922).
[3]C. J. Hudson, J. Am. Cer. Soc. 4, p. 738 (1921).
[4]Sproat and Allbright, J. Am. Cer. Soc. 3, p. 460 (1920).
[5]J. T. Jans, T. Am. Cer. Soc. VII, p. 626 (1924).

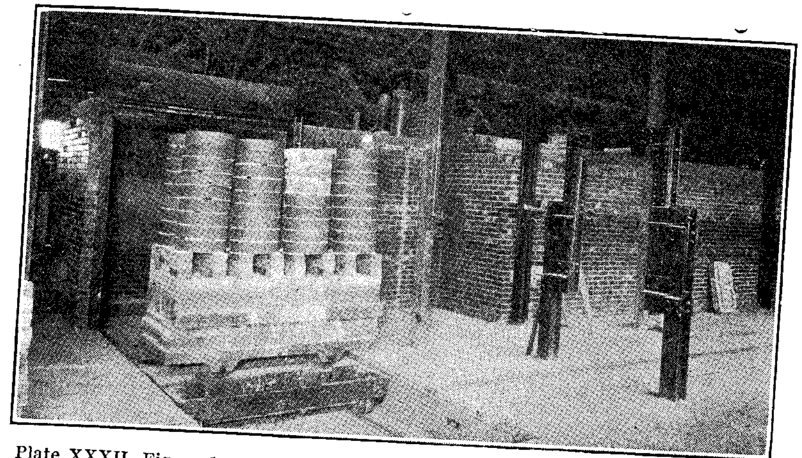


Plate XXXII, Figure 1.—Saggers containing spark plug cores loaded on car ready to be charged into Dressler kiln, Champion Porcelain Co., Detroit. (From Fuels and Furnaces 2 p. 35,—1924.)

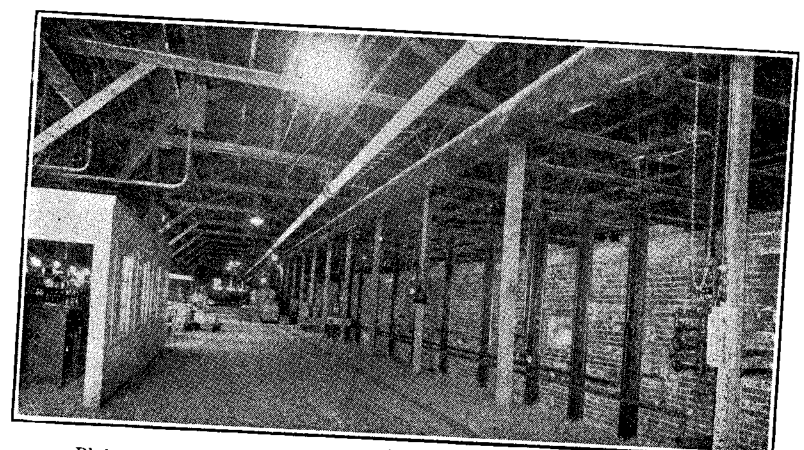


Plate XXXII, Figure 2.—Kiln room Champion Porcelain Co., Detroit. (From Fuels and Furnaces.)

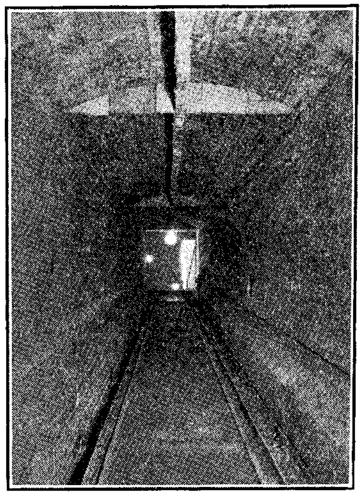


Plate XXXIII, Figure 1.—Horizontal draft tunnel kiln with central baffle for cross draft operation.
(From Fuels and Furnaces 3 p. 130,—1925.)

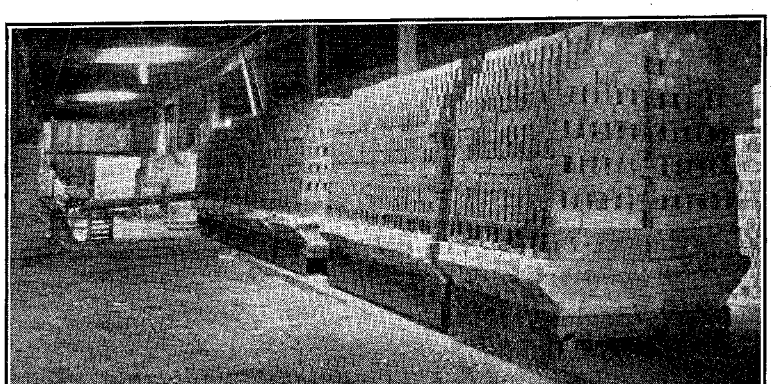


Plate XXXIII, Figure 2.—Burned fire brick at exit of direct fired single tunnel cross draft Dressler kiln.
(From Fuels and Furnaces 3 p. 131,—1925.)

transverse flues to heat the kiln air, drop arches and baffle walls are used to bring the kiln air into intimate contact with the carborundum muffle. This kiln is 125 feet long, and produces 3,000 dozen dinnerware per 24 hours. The cars are pushed continuously at the rate of about 4 or 5 inches per minute. The kiln is oil fired. A similar kiln equipped to burn natural gas or oil has also been constructed for the same use at the Homer Laughlin China Co., plant C, Newell, W. Va. This kiln has automatic temperature control to within $\pm 10°F$. These kilns are reported to be very satisfactory giving an excellent product when operated by comparatively unskilled labor.

Direct Fired Cross Draft Tunnel Kiln.

Plate XXXIII, Fig. 1, shows the interior of a direct fire horizontal draft tunnel kiln, designed to force circulation of the hot gases through the lower part of the ware. The kiln is provided with a baffle in the center of the crown and running the length of the preheating zone to prevent the gases from passing over the ware from side to side as the draft is reversed from one side to another. Off-take flues on each side of the kiln communicate with the interior through ports and are independently connected to the exhausting fan through a reversing valve. At each reversal one-half of the gases in finding their way from the space between the ware and the kiln walls are obliged to pass through the ware.

Figure 64 shows a cross section of a single track Dressler Transverse Draft, Direct Fire Tunnel Kiln designed along these lines. Plate XXXIII, Fig. 2, shows cars loaded with burned fire brick at the exit end of this kiln with cross reversal of draft.

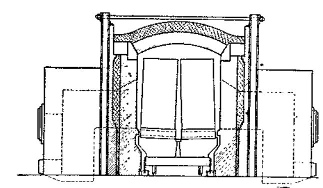


Figure 64.—Dressler transverse draft kiln.

Figure 65 shows in cross section the construction of a double tunnel direct fired transverse draft regenerative kiln as built by Dressler for the Kreiselier Brick Company, Tottenville, Staten Island, N. Y., and used for firing refractories.

The gases pass transversely across the kiln, making each zone practically independent, and compelling the gases to pass through all parts of the stacked ware. For these reasons cars of much greater width can be used than in the horizontal draft tunnel kilns, but regenerators are necessary to recover the heat in the gases which do not preheat the ware. Section BB on the right hand half shows the double regeneration used in the furnace zone. Section AA on the left hand half shows the single regenerator used in the preheating zone. On either side of the furnace zone the outgoing cars are heating up the incoming cars on the other track by a similar cross draft. Section A-A on the left half shows the single regenerator used in the preheating zone. Some gas is burned on the outside of the incoming car to insure even heating. At the entrance end of the kiln heat interchange takes place exclusively by natural circulation between the cooling and heating cars. In this way the heating of each combustion chamber can be separately controlled and very wide kilns are evenly burned.[1]

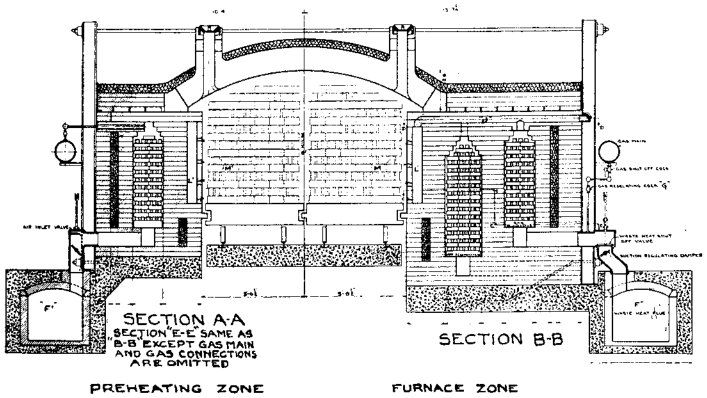


Figure 65.—Double tunnel transverse draft. (From Fuels and Furnaces.)

Summary. The first tunnel kiln in America was a twin tunnel built by J. C. Anderson in 1889 at Chicago for firing dry pressed brick.[2] In 1899 a similar kiln was built at Tottenville, Staten Island. Railroad flat cars were used to carry the ware in this kiln. Neither kiln operated for any length of time.

Mrs. F. D. Shaw built a number of tunnel kilns beginning 1908, at Judson, Ind., near Louisville, Ky., and at Trenton, N. J. All of these kilns were failures.

In 1910 two Faugeron kilns were built for the Didier-March Co. at Keasbey, N. J. One of these operated successfully for about eight years. A kiln of the same type was built by the General Electric Company at Schenectady, N. Y., in 1913.

The first Dressler Kiln was built in 1915 at New Castle, Pa. In 1917 the first Russell or Zwermann kiln was built at Kalamazoo, Mich., and the first Harrop kiln in 1919 at New Cumberland, W. Va.

At present there are 112 or more tunnel kilns in this country, and Canada, 75 for burning porcelain, sanitary ware, tile, and similar products; and 23 for burning brick, terra cotta, and heavy clay products.

[1]P. Dressler, J. Am. Cer. Soc. 8, p. 43 (1925).
Brick and Clay Record 66, p. 25 (1925).
[2]The Clay Products Cyclopedia.
Brick and Clay Record 66, p. 23 (1925).

Although the original cost is high, the tunnel kiln, when properly adapted and operated, offers many important advantages:

1. Constant firing conditions and fire at one place only.
2. Fuel saving due to regeneration or preheating of air and ware.
3. Reduced burning time.
4. Better burned product.
5. Less handling costs and reduced labor charges.

On the other hand water smoking and oxidation, and soaking and cooling can be successfully accomplished with capacity production only when the kiln is properly designed and operated to suit the burning requirements of the clay.[1]

Both types of kilns, the muffle and the direct fired, have proved successful in burning almost all kinds of products with a fuel saving of 60 to 85 per cent,[2] over that of the periodic down draft kilns.

GENERAL DISCUSSION

Kilns. The very crude intermittent up-draft scove kilns give the poorest control and the poorest product of any kiln. For this reason this type of kiln can be used for burning common brick only. The permanent wall up-draft kiln is essentially an improved scove kiln and may be used for drain tile as well as common brick. However, the use of an up-draft kiln for tile of any kind is usually unsatisfactory and is not generally to be recommended. These kilns are cheaply constructed, give a poor product and are wasteful of fuel, although they do not use an excessive amount of fuel considering the crudeness of the process.

The intermittent down-draft kilns usually circular, offer much better heat distribution and are suitable for almost all kinds of clay products from common brick to the highest grade electrical porcelain. This type of kiln is more expensive to build and to operate than the scove kiln but offers advantages in turning out a better product. These kilns should be built rather low, not over 12 feet from floor to crown in the center, and supplied with a generous number of furnaces, preferably 10 or 12 for a kiln 30 feet in diameter. The lower the kiln the easier it is to burn the bottom tiers, and a large number of furnaces make for even heat distribution around the kiln. This type of kiln is notoriously wasteful of fuel particularly if the kiln bottom is exposed to moisture. The following distribution of the heat in a down draft periodic kiln may be taken as representative of good practice.[3]

[1]Brick and Clay Record 66, p. 23 (1925).
Ellis Lovejoy, J. Am. Cer. Soc. 1, p. 628 (1918).
[2]Harrop, Trood, and Brain in J. Am. Cer. Soc. 3, p. 697-721 (1920).
Greaves, Walker & Kier, J. Am. Cer. Soc. 6, p. 891 (1923).
[3]Report of Committee on Fuel Conservation, J. A. Cer. Soc. 5, p. 601 (1922).

Heat in the ware	12%
Heat lost in waste gases	25%
Heat lost in ashes	4%
Heat lost in kiln and by convection...	59%

Continuous kilns of all kinds must be operated continuously to be of any advantage. This means that the rest of the plant must maintain a daily production sufficient to keep the kiln working to capacity. If this condition is met and the kiln properly designed, constructed and operated, a continuous kiln of the correct type for the product will prove successful and economical, producing a better, more uniform product with a saving in fuel of one-half or more.

The continuous tunnel kiln of the Hoffman type has proved very successful in burning all kinds of brick. The continuous compartment kiln of the Mendheim type has the advantage of down-draft heating and a wider range of application. This type of kiln can be used to replace a number of intermittent down-draft kilns with a saving in fuel of from 50 to 70 per cent, and will occupy much less space in the kiln yard, greatly reducing the work of transporting the ware to and from the kiln. As at least two chambers, one unloading and one loading, are cool at all times repairs can be made easily on these chambers without shutting down the kiln. The alternate heating and cooling of the furnace walls as the fire passes around the kiln is hard on the furnace structure and makes repairs necessary.*

The continuous car tunnel kiln is the ideal type for all purposes. The continuous car tunnel kiln is a proved success for all types of high grade ware; pottery, porcelain, and sanitary ware, being fired, glazed, and decorated successfully in this type kiln in Michigan, and refractories as well as these products being efficiently burned elsewhere. In burning low grade clay products such as brick, tile, and pavers, the long oxidation period at constant temperature necessary for the proper oxidation of the iron and sulphur, offers difficult problems in design and operation that are gradually being solved in long kilns. Compared to the continuous chamber kilns the car tunnel offers advantages in less handling of the ware and usually less kiln repair, but the latter must be carefully controlled to obtain the best results. When properly controlled and adapted, the continuous car tunnel kiln produces the best results on high grade ware, and it is logical to expect equally satisfactory results on the heavy clay products when this type of kiln is developed for these products. In this country the Dressler kiln is the only muffled car tunnel kiln in general use, and has proved very satisfactory even for the highest temperatures (cone 20). The direct fired type is cheaper to

[1]W. D. Richardson "Continuous Gas Fired Compartment Kiln for Clay Products." J. Am. Cer. Soc. 5, p. 255 (1922).

build and is now developed to give equally satisfactory results for most purposes where the muffled flame is not required.

Kirk[1] reports that a Dressler kiln firing sanitary ware burns about 15,000 pounds of ware in 24 hours consuming about 25,000 cubic feet of natural gas, and that about ten times as much gas was required to burn the same amount of material in periodic down draft kilns. These figures are extreme, probably due to the fact that natural gas gives a rather short flame and is an ideal fuel for tunnel kilns and a very poor fuel for intermittent down draft kilns as the short flame would make it very difficult to burn the bottom of the kiln, unless a large amount of air was used to carry the heat evenly through the kiln. Under such conditions the stack losses are excessive, while in the muffled tunnel kiln the gas can be burned with practically no excess air and cooled to 200° or 300°C so that the stack losses are very small. Usually continuous recuperative or regenerative kilns require from one-half to one-quarter as much fuel as intermittent down-draft kilns.

Present Trend in Brick Manufacture. The largest part of the work in a brick yard is material handling, yet most of this work is still done by hand and man power. In making 1,000 bricks 6,000 to 7,000 pounds of clay must be dug, conveyed to the plant, and molded, the green brick must be taken off two at a time in stiff mud plants, conveyed to the drier, and about 1,500 pounds of water evaporated by heat from the combustion of about 300 pounds of coal; the dried bricks must be set two to five at a time in a kiln, burned by about 600 or more pounds of coal, loaded on barrows, and from the barrows into cars 4 to 6 at a time. For 1,000 bricks, three tons of clay are handled six times in small lots and transported the entire length of the plant, and about one-half ton of coal is moved and shoveled two or three times.

Most of the yards use hand power and horse power. Wages are low and the work is heavy. These conditions are unfavorable to the brick industry as compared to others in which mechanical handling of materials is widely applied and highly developed. While some systems of mechanical handling of green brick have been tried, most yards, particularly those using the stiff mud process, do most of it by hand. The soft mud brick is generally conveyed into the drier on the original pallet which received the brick from the molding machine, and out of the drier to the kiln shed, on a truck.

The Fiske[2] *system* was a radical departure from established practice. The stiff mud bricks were racked directly from the take off belt in units of 1,500 on forms resting on the floor. The rack was picked up by an electric crane and lowered into an open top drier. Later the drying was

[1]Trans. Am. Cer. Soc. XVIII, 535 (1916).
[2]J. Parker Fiske, Trans. Am. Cer. Soc. V, p. 21?(1903); IX, p.?799 (1907).

done by setting the rack of green bricks on top of the cooling kilns. From the drier the rack was similarly placed in an open top continuous kiln with a removable crown.

Following the initial Fiske installation, a somewhat similar system for dry pressed brick was installed using a single overhead track to convey the bricks in smaller units and a crane to set them in the kiln.

Penfield system. In Chicago[1] the bricks are placed on cars from the take-off belts in units of 600 to 1,000, the setting corresponding to that required in the kiln, arch, bench, head, casing, and regular units. The cars are run into the drier by motor power. When dried the units of bricks are picked up by a crane and placed in the proper place in the scove kiln (Plate XXXIV).

The Scott system, originally employed at Knoxville, Tenn., applied to stiff mud bricks extends the take-off belt conveyor from the molding machine the full length of the kilns. A cross conveyor carries the bricks into each kiln or chamber where they are set 6 to 8 or 12 courses high. The bricks are dried at night or over a longer period, during which the next day's production may be set in another kiln. Then the cross conveyor is raised and a second setting of 6 or 8 courses is laid on top of the dried brick. This process continues until the kiln or chamber is filled. While this plan does not eliminate handling entirely, it greatly reduces labor in moving and handling brick into the kiln and the brick have to be set as fast as they are delivered to the kiln or they are dumped off the end of the conveyor as mute evidence of slack work or insufficient setting force. In discussing "Brick at Less Cost" W. D. Richardson[2] describes the method of working this system at the Builder's Brick Co., Chicago, and at New Hope, Pa. For economical burning and drying of brick laid in this way an open top continuous chamber kiln equipped with portable arches is recommended. The brick can be switched from the long main conveyor to the side conveyor leading into the open chamber. Twelve courses may be set and then dried by advance heat blown in from under the chamber floor by a portable fan. Twelve more courses are set, the door casing dropped in, and the drying continued on the up-draft principle as above. The portable arches are then removed from a cool chamber and set over the last chamber of brick, which is then burned in the manner usual to a continuous chamber kiln.

This type of kiln using heat obtained from cooling brick to dry the green brick without extra consumption of fuel, and in the same setting in which the brick are to be burned is a natural logical development of the use of continuous kilns. Dressler proposes to dry the ware on the same car on which they are to be burned by taking air from the heating

[1]Brick and Clay Record 66, p. 108 (Jan. 20, 1925).
R. C. Penfield, Clayworker 75, p. 241 (1921).
[2]J. Am. Cer. Soc. VII, p. 614 (1924).

zone of the muffle kiln and passing it through pipes in a drying tunnel with the object of recovering not only the sensible heat in the hot air but also a large part of the latent heat of the water vapor evaporated from the ware in the heating zone, and condensed in the pipes in the drier.

The separately heated drier is rapidly becoming out of date in any plant using a continuous kiln, and intermittent kilns are practically obsolete except in small plants which do not make enough ware to keep a continuous kiln running or those plants which operate only a few months of the year.

As the car tunnel kiln becomes more generally used and adapted to burning brick mechanical handling in common brick plants may be greatly simplified by drying and burning the brick on the same car. As drying, water-smoking, and oxidizing are essentially continuous developments of the same process it seems reasonable to expect that these operations can be efficiently conducted as a continuous process.

PORTLAND CEMENT[1]

Definition. Portland cement is the finely ground clinker obtained by heating an artificial mixture consisting essentially of lime, silica, alumina, and iron oxide, properly proportioned, to a clinkering temperature or incipient vitrification (1400°-1500°C). It possesses the ability to set or harden under water. For practical reasons the term is restricted to only those cements made in a fairly definite manner from a somewhat restricted class of raw materials. Portland cement may be defined as the finely pulverized product obtained by calcining to incipient fusion an intimate artificial mixture of argillaceous (clay) and calcareous (lime) materials, this product to contain not less than 1.7 parts by weight of lime to one part by weight of silica plus alumina plus ferric oxide,[2] not more than 4 per cent of magnesia, not more than 1.75 per cent of anhydrous sulphuric acid (SO_3), and to which no addition greater than 3 per cent shall have been made subsequent to calcination.

History. Hydraulic cements were probably used in North America by the Mound Builders. The Egyptians and Romans used hydraulic cements in the construction of the pyramids, aqueducts, and public buildings. Through the period of stagnation known as the "Middle Ages" the making of cement and concrete appears to have become a lost art. John Smeaton, an English engineer, began in 1756 a series of experiments to find a cement more satisfactory than lime for rebuilding the Eddystone lighthouse. He discovered that the calcination of an argilla-

[1]Portland Cement, Richard K. Meade, Chemical Publishing Co. (1911).
Cement, Bertram Blount, Longmans Green & Co.
The Manufacturer of Portland Cement, West
The Portland Cement Industry, W. A. Brown.
The Cement Industry, Engineering Record, 1900.
[2]This ratio is usually maintained very close to 2 by the Michigan plants.

ceous limestone gave a product superior in every way to ordinary lime and possessing the property of setting under water. In 1824 Joseph Aspden, a brick mason of Leeds, England, patented a method of making cement by burning a mixture of clay and limestone dust and grinding the product. Because of a real or fancied resemblance of this cement to a limestone known as Portland stone, Aspden called his cement "Portland cement."

In 1818 Canvass White, an engineer on the construction of the Erie Canal discovered the natural cement rock in Madison County, New York. The natural cement patented and made by White was used in large quantities in the construction of the canal. In 1866 an unsuccessful attempt was made to obtain hydraulic cement by calcining impure limestone at Trowbridge dam, on Thunder Bay river, seven miles northwest of Alpena. Wood was used as a fuel. So far as is known this is the only effort on a commercial scale to manufacture "natural cement" in Michigan.

In 1872 the first attempt to manufacture Portland cement in Michigan, if not in the United States, was made by the Eagle Portland Cement Company of Chicago[1] at a plant about two miles northeast of Kalamazoo. The plant originally consisted of two circular kilns about 16 feet in diameter, shaped much like a beehive oven. The marl and surface clay obtained locally were mixed, air dried, cut into rude bricks which were more thoroughly dried over furnaces fired with wood. The bricks were then put in the kilns with alternating layers of coke and calcined by the burning coke. The clinker was ground by mill stones and sold wholesale for $4.00 a barrel. This plant continued production at about 100 barrels a day until 1882.

The Peerless Portland Cement Company built their plant at Union City in 1896-97, followed immediately by the:

Bronson Portland Cement Company, Bronson[2]
Michigan Portland Cement Company, Coldwater and Quincy[3]
Michigan Alkali Company at Wyandotte
Omega Portland Cement Company, Mosherville

These plants produced 600,934 barrels of cement in 1900. The average selling price was about $1.65 per barrel. All of the above plants used marl as the source of lime except that of the Michigan Alkali Company which used the calcium carbonate precipitated as a waste product in the manufacture of alkali. With the exception of the Alpena plant which used limestone from the beginning, all of the companies erecting plants in Michigan in the years immediately following 1900 also used marl as the source of lime. This tendency to use marl instead of the more satis-

[1]I. C. Russell, U. S. Geol. Survey, 22d Annual Report, Part III, p. 635 (1902).
[2]F. H. Lewis, p. 33, The Cement Industry, Eng. Record (1900).
[3]F. H. Lewis, p. 78 Ibid.

factory limestone may have been partly due to the excellent report on Marl[1] published by the Michigan Geological Survey in 1903. In any case the industry saw a rapid speculative expansion during this period with practically all of the plants located on marl beds. The six plants mentioned above were built from 1897 to 1900. Twelve more were constructed from 1900 to 1903 and about 25 new companies organized in the same period. Many of the companies organized never erected plants, some plants failed, and nearly all plants have abandoned marl beds and are now using limestone. This early experience of the cement industry is very similar to that of the brick and tile industry. Too many plants, poorly located, using poor material, cause an oversupply and result in many failures.

Composition and Properties. The active ingredients of Portland cement are essentially compounds of calcium with silica and with alumina, (among others tricalcium silicate and dicalcium aluminate). Free silica[2] will not readily react with calcium to form the calcium silicate, but if the silica is combined with alumina as in clay and shale, the desired reaction will occur readily in the kiln. Iron and some lime are of advantage in the clay in making it fuse readily, and therefore combine easily with the lime. For these reasons sand in either the limestone or clay is very undesirable and the clay must be depended upon to supply the necessary silica.

Iron is also of advantage in the clay used for Portland cement because the iron compounds set more slowly than the calcium aluminate, making it necessary to add less gypsum. The rapid setting of calcium aluminate made this compound very useful in preparing trench fortifications during the recent war. If lime and alumina are mixed so that the mixture contains 55-75 per cent of alumina, and the mixture is burned and ground as in preparing Portland cement, the ground clinker sets in 24 hours, having the same strength that Portland cement develops in 28 days.[3]

Methods of Manufacture. Before the mixture of clay and limestone can be burned these materials must be very finely ground and mixed in the proper proportion. In many plants the raw materials are ground and mixed according to their analysis and no check analysis is made after mixing, although this last step is desirable for good control. The grinding and mixing may be done dry as in the dry process, or in a slurry of from 30 to 50 per cent water as in the wet process. The wet process is necessary when using marl and offers advantages in washing the raw materials, grinding and preventing loss through dusting, but usually consumes more fuel, even when longer kilns are used. The early

[1]D. T. Hale, Mich. Geol. Survey VIII, Part III, "Marl and its Application to the Manufacture of Portland Cement." (1903)
[2]Klein & Phillips, U. S. Bur. Standards Technologic Paper 43.
Mills "Material of Construction", John Wiley & Sons.
[3]P. H. Bates, J. Am. Cer. Soc. 1, p. 679 (1918).
H. S. Spackman, Proc. Am. Concrete Inst. 20, p. 348 (1924).

plants throughout the country used the wet process with kilns about 60 feet long. The dry process using shorter kilns about 40 feet long came into favor about 1900. In order to get greater fuel economy the kilns were later lengthened, and with the longer kilns the wet process seems to have the upper hand again even though most of the Michigan plants are using limestone and shale. This is due the greater ease in producing a uniform product with the wet process.

Dry Process. The limestone and shale are crushed to about 2 or 2½ inch pieces and stored under cover. In the dry process the material is then dried to prevent clogging the mills. The dried material is ground usually in some form of ball mill or kominuter followed by thorough mixing and fine grinding in a tube mill or Fuller-Lehigh mill. Fine grinding of the raw material is probably the most important factor in producing satisfactory cement. The ground mixture is then fed into the upper end of a rotary kiln by a screw conveyor belted to the kiln so that feeding starts and stops with the kiln. The kiln is usually about 8 to 11 feet in diameter and 100 or 200 feet long and set with a pitch of about ¾ inch to a foot.

Powdered coal is used as a fuel. The coal is crushed, dried, and ground in much the same way as the limestone. The powdered coal is delivered by mechanical or pneumatic conveyor from the grinding mills to bins located above and behind the burner end of the kiln. From this bin it is fed into an air blast which conveys the coal through a pipe to a nozzle projecting a foot or so into the kiln. The air so introduced is usually about one-fourth that required for combustion, a large part being drawn in by the natural draft of the kiln stack through the opening in the hood where the clinker is discharged. Proper burning is determined largely by the color and appearance of the clinker, the properly burned clinker being a greenish black in color with a vitreous luster showing bright glistening specks when just cooled. The clinker is usually discharged in lumps which vary in size up to about that of a walnut. Underburned clinker is brown or has brown centers and lacks the luster of that well burned. The burning accomplishes the following reactions approximately in the sequence given:

- Evaporation of water
- Dissociation of limestone into quick lime and carbon dioxide
- Expulsion of alkalies (sodium and potassium oxides)
- Oxidation of iron to ferric condition
- Combination of lime (and magnesia) with silica, alumina, and ferric oxide to form the calcium silicates, aluminates, and ferrates constituting Portland cement.

With the exception of the first action and possibly some dissociation of limestone, all these reactions occur in the last 60 to 85 feet of the kiln,

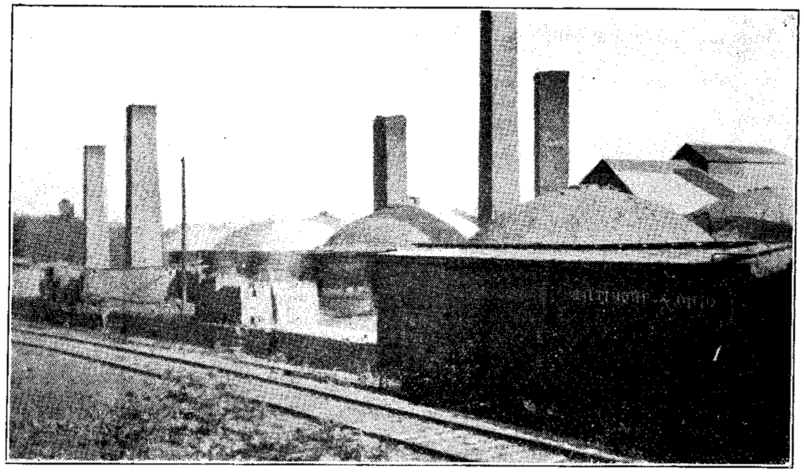


Plate XXIV, Figure 1.—Section of kiln yard of Corunna Brick Co., Corunna. Shiawassee County.

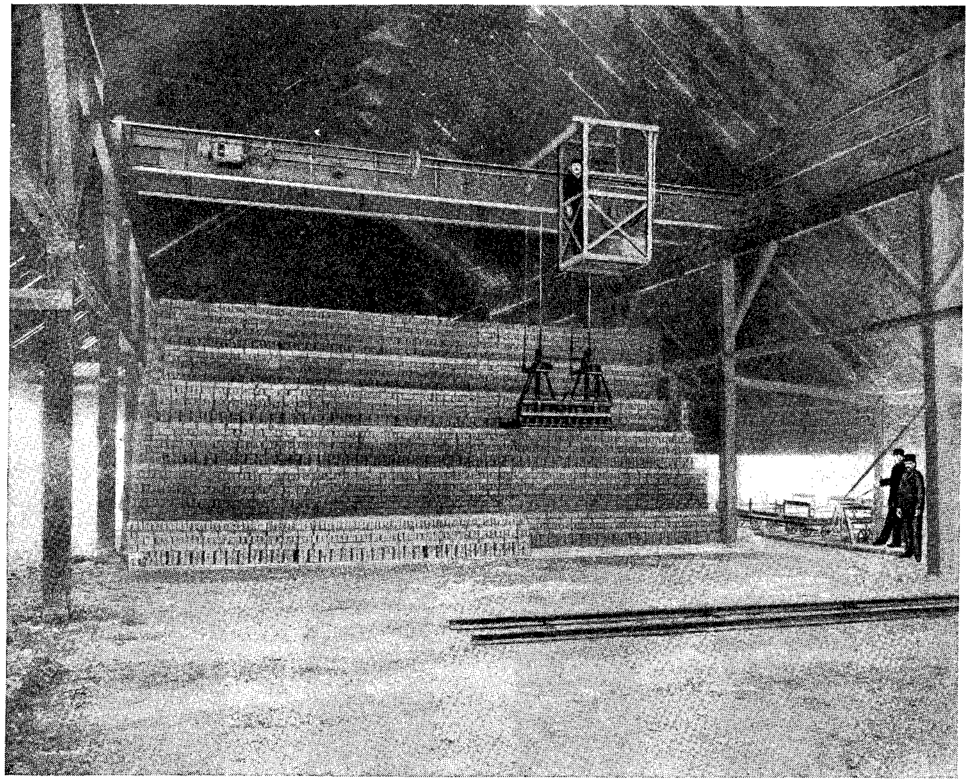


Plate XXXIV, Figure 2.—Penfield method of setting scove kiln, Chicago, Ill. (From Hadfield-Penfield Steel Co.)

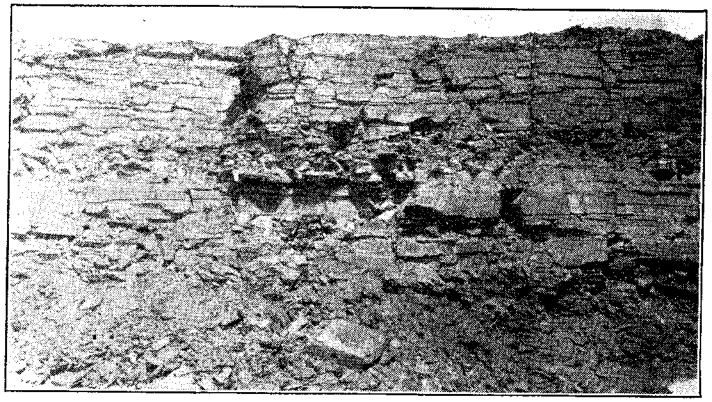


Plate XXXV, Figure 1.—Shale in Paxton Quarry, Alpena County.

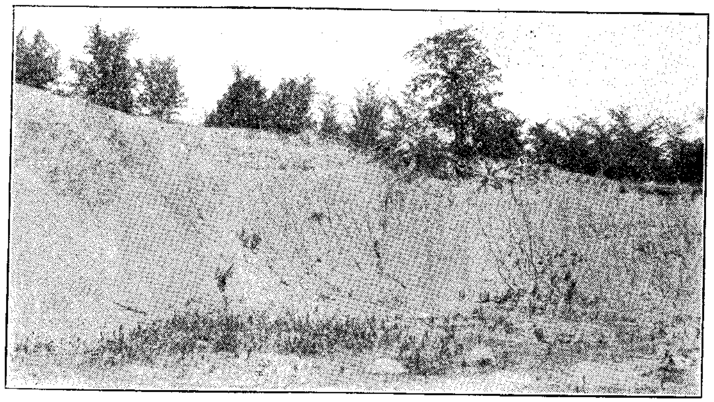


Plate XXXV, Figure 2.—Clay, Grand Rapids Brick Co.

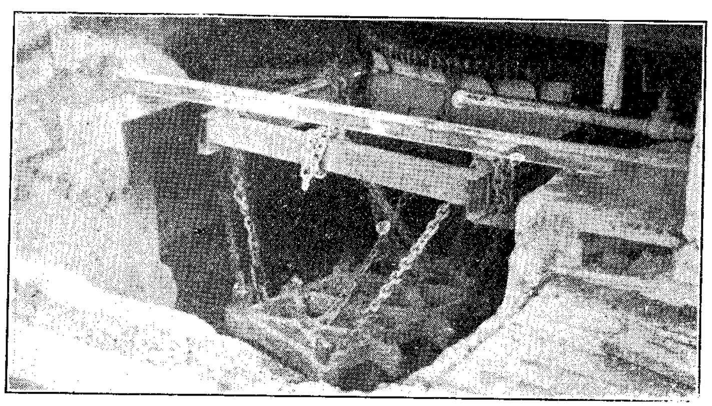


Plate XXXV, Figure 3.—Clay disintegrator, State Cement Plant, Chelsea.

the extra length serving only to dry and preheat the raw material by heat that would otherwise be carried off by the stack gases. The heat in the hot clinker may be partially recovered by drawing the air used for combustion in the kiln through the hot clinker in a rotary cooler, thus cooling the clinker and preheating the air. The large amount of heat in the stack gases may be partially used by passing the hot gases through rotary driers used to dry the raw material, or through a "waste heat" boiler. The dust in the kiln gases when the dry process is used causes rapid abrasion and early failure of the boiler tubes. The temperature of the gases from a wet process kiln is much lower and until recently waste heat boilers were considered unprofitable in wet process plants. Some of the Michigan plants have installed, or are installing, waste heat boilers on kilns using the wet process.

After being cooled the clinker is very finely ground in the same type of equipment as used for grinding the raw material. If the clinker is not finely ground it is inert and practically equivalent to so much sand. I. A. Williams* claims that about one-half of commercial cement is inert and recommends that the clinker be ground so that not more than 8 per cent be retained on 100 mesh and not less than 75 per cent pass through 200 mesh. The ground clinker is generally quick setting and gypsum ($CaSO_4 . 2H_2O$) is usually added in small amounts up to about two per cent to retard the setting. The finished cement is packed in barrels containing 380 pounds, or in cloth or paper sacks containing 95 pounds net.

Wet Process. In the *wet process* the clay is thoroughly slaked in a washer or disintegrator (Plate XXXV, Fig. 2), passed through gratings in the periphery of the washing pit and the slurry containing about 60 per cent of water pumped to storage tanks. The pulverized limestone is mixed wet with the clay and ground wet in ball or tube mills. The succeeding treatment is similar to that given the material in the dry process except that the wet slurry containing from 30 to 45 per cent water is pumped into the kiln instead of conveyed by a screw conveyor. The wet process offers advantages in better control, more intimate mixing of the raw material, and less loss in dust up in the stack and in grinding, but usually requires more fuel to evaporate the 30 to 40 per cent of moisture although the temperature of the stack gases is much lower indicating much less heat loss in sensible heat up the stack. Fine grinding of the raw material increases the fluidity of the slurry and is particularly essential in the wet process. The water content of the slurry fed to the kiln may be reduced to 30 per cent without causing pumping difficulties if the slurry is finely ground.

[1]Trans. Am. Cer. Soc. 10, p. 244 (1908).

PART II

TESTS OF MICHIGAN CLAYS AND SHALES

Chapter VIII

TESTS OF MICHIGAN CLAYS AND SHALES

EXPLANATORY STATEMENT

Maps. All of the surface clays of Michigan are of glacial or recent origin. Many deposits, particularly in the northwestern and eastern portions of the Northern Peninsula and along the eastern side of the Southern Peninsula, are true lake clays, at least at the surface, deposited as muds in the beds of former glacial lakes. They are fine grained and practically without pebbles. The rest of the clays are largely glacial till, a direct mechanical deposit by the ice sheet during the Ice Age,* and they contain more or less coarse sand and pebbles or boulders.

The mineral and chemical composition of these glacial clays, especially the boulder clays, generally varies rapidly vertically and horizontally. The properties of these clays vary correspondingly within wide limits, even in the same deposit. For these reasons it is practically impossible to indicate on the map (Fig. 67) areas containing clays of any particular kind or properties. A given area on the map indicates that a sample of clay of certain properties and possible uses was taken from that area and that similar clay may possibly be found elsewhere within it. Thus an area showing clay suitable for face brick means simply that a sample of clay taken from that area showed properties indicating that the sample might be used for face brick. It does not mean that the area is covered with clay suitable for face brick manufacture unless that statement is made definitely in the text.

The maps were prepared as an aid in understanding and summarizing the more accurate and detailed statements in the complete report, and must not be used except as subordinate to the text.

Description by Counties. Because it is impossible to describe intelligently the clays of Michigan in detail according to any geological classification, the State has been divided into its two natural subdivisions (The Northern and Southern Peninsulas) and the clay and clay industries described in detail according to counties. By the use of the maps

*Mon. LII, Pleiistocene of Indiana and Michigant, by Leveret and Taylor, U. S. Geol. Surv., 191i Pub. 25, Geol. Ser. 21, Surface Goelogy of Michigan by Frank Leverett, Mich. Geol. and Bioo. Surv., 1916.

and the index, which list all descriptions by number and kind, as well as by counties, any available information is readily accessible.

The location from which the sample was taken has been given in as definite and exact terms as possible. Peculiar local conditions, old and present workings, and encountered difficulties have been described so that the possible economic value of each deposit may be better estimated.

Sources of Information. Old records and reports have been consulted and all important data included in the present report.

For general or preliminary information the following descriptions are essentially a complete record of all the available information. References have been given so that original sources may be consulted if desired.

Methods of Sampling. In taking samples the methods used were in general those outlined in chapter two on prospecting for clay. It is obviously impossible to sample and test every individual pocket of glacial clay, so an effort was made to sample so far as possible the representative clays of each district to obtain a general idea of the probable utility of the clays found in different parts of the State. The samples obtained by trenching, from the auger, or by other means were generally reduced to about 25 pounds in the field. The reduced sample was bound in a small, tightly woven sack of awning material, properly labeled, and carried in the car until a freight office was reached. The small sacks were then combined in larger sacks and shipped to the laboratory.

Methods of Testing. All tests were conducted in the Ceramic Laboratories (Plate XXXVI) of the Department of Chemical Engineering, University of Michigan, Ann Arbor, unless otherwise noted.

Because of the large number of tests necessary to indicate adequately the possible uses of Michigan clays, the testing was reduced to the simplest possible routine, and consisted simply of the drying and burning tests. These tests are adequate to determine fairly accurately the possible uses and value of the clay sample. The more specialized tests on plasticity, texture, warpage, transverse strength, etc., were omitted as unnecessary for the present purpose of indicating the possible uses of Michigan clays in a general survey of the entire State.

The clay samples as received at the laboratory were crushed and reduced to about three pounds. If the sample were of shale the sample was ground in the dry pan and screened to pass 40 mesh and then reduced by quartering as described in the second chapter.

The reduced sample was tempered with the requisite amount of distilled water to develop its maximum plasticity. The mixing was done thoroughly in small Werner & Pfleiderer mixers. The plasticity was judged by feel.

When properly tempered the clay was wedged into a cylinder and extruded in a screw press through a die of about 1 x ¾ inches. The

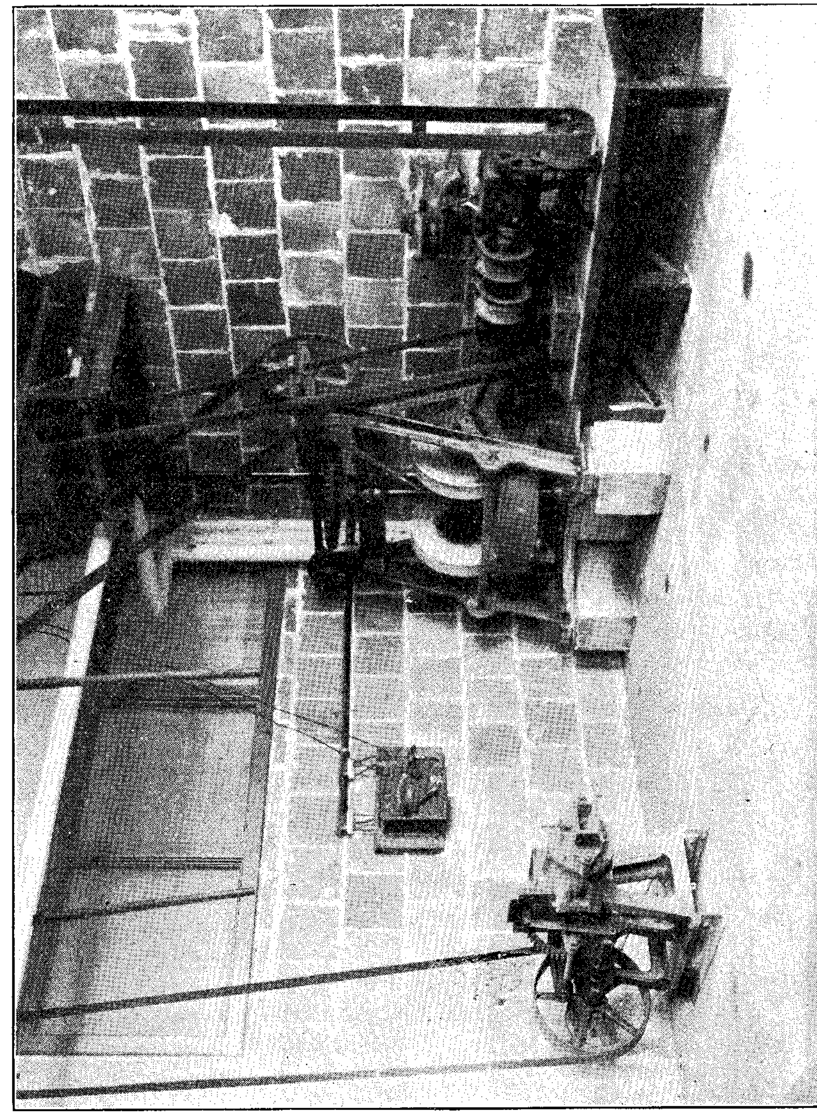


Plate XXXVI, Figure 1.—Corner in clay preparation room. Department of Chemical Engineering, University of Michigan.

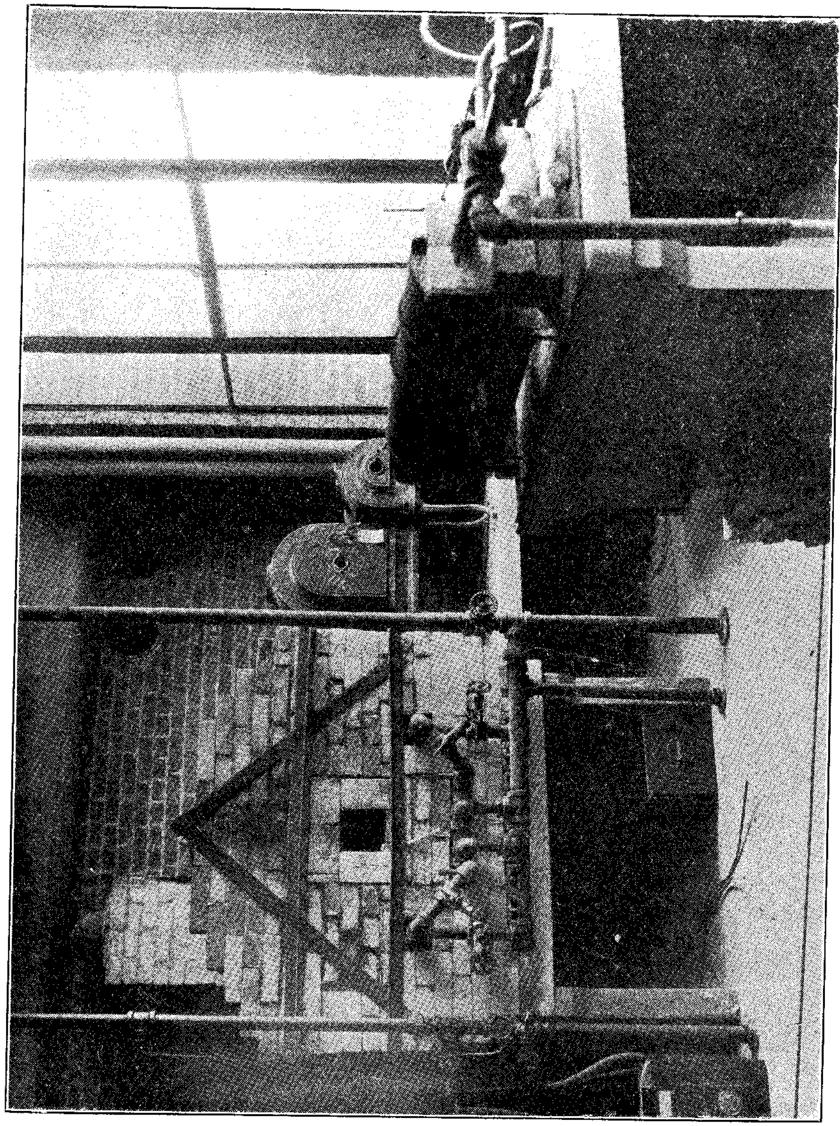


Plate XXXVI, Figure 2.—Corner in kiln room. Department of Chemical Engineering University of Michigan.

column of clay was then cut into briquetts about two inches long which were numbered with the sample number and also given a serial number.

The plastic weight of the test brick was determined immediately. Then the plastic volume was determined in a volumeter filled with kerosene.

The bricks were then blotted dry of kerosene and allowed to dry at room temperature until air dry. They were then dried in an electric drying oven at 70°C. for five hours, and finally 110°C. to approximately constant weight. The dry bricks were weighed and then placed in a dessicator. Water of plasticity was determined as the number of grams of water evaporated per gram of dry clay.

The dry volume was determined by soaking the dry test bricks in kerosene as used in the volumeter for at least twelve hours, and then measuring the volume as before. The volume shrinkage was computed as a per cent of the dry volume. The drying shrinkage is reported for convenience as linear shrinkage in per cent of the dry length. The linear shrinkage $= \left(1 - \sqrt[3]{1 - \frac{b}{100}}\right) \times 100$ where b = volume shrinkage.

The bricks were then blotted dry and replaced in the drier to remove most of the absorbed kerosene. When this had been accomplished the test bricks were stood on end on the floor of the down draft testing kiln (Plate XXXVI). This kiln is a recuperative gas fired kiln with an effective space of about five cubic feet. It was built specially for this work and has proved very satisfactory. The samples were stacked in rows from front to back of the furnace with a row of pyrometric cones from 012 to 9 running down the center. In this way one brick from each row was removed as the corresponding cone went down and the next bricks to be removed were always in the front of the rows. In order to control the rate of heating a thermocouple with its hot junction adjacent to the row of pyrometric cones was always used.

Burning was done with an excess of air to aid in oxidizing the clay. Except in special cases of clays that had to be thoroughly oxidized at about 500°C. the temperature was raised about 100°C. an hour to 750°C. and held constant until the dark centers of drawn bricks were completely oxidized. Then the temperature was raised about 50°C. an hour until the clay melted. The above rates of heating are about twice those recommended in the standard method. Comparative burns at the slower rate showed no noticeable differences on cones or Michigan clays and the faster rate was used.

Test bricks were drawn at intervals of two cones, beginning at cone 010 and placed in the vestibule of the furnace to cool slowly until time to draw the next test specimens. The bricks were then removed from the vestibule and placed in hot sand to finish cooling. When cool enough to handle the bricks were placed in a dessicator until weighed.

The burned bricks were then saturated with boiling water for four hours, and cooled under water. The saturated weight was then taken The volume of the saturated brick was then taken in a volumeter containing water.

The apparent porosity is computed as the volume of water absorbed per unit volume of burned clay.

The apparent specific gravity is computed as the weight in grams per apparent unit net volume of burned clay. (Apparent net volume = fired volume minus volume of absorbed water).[1]

The color of the burned brick was compared against a chart and carefully noted.

Hardness of the brick was determined by a piece of rounded steel and reported as soft if easily scratched, and hard if not scratched. As porosity varies with hardness, porosity should also be considered in comparing hardness.

The above data were plotted as an aid in determining the possible uses of the sample of clay.

All sample numbers prefixed "R" are samples taken and tested or reported by Ries in the survey of 1900.[2]

The shrinkage reported by Ries is the total shrinkage or the shrinkage based on the length of the plastic clay instead of the dry clay as 100 per cent. The total shrinkage expressed as per cent of plastic length may be converted to dry and fire shrinkage as follows:

$$D.s.d = D.s.p \times \frac{100}{100 - D.s.p}$$

$$F.s.p = T.s.p - D.s.p$$

$$F.s.d = F.s.p \times \frac{100}{100 - D.s.p}$$

where

D.s.d. = Drying shrinkage expressed as per cent of dry length.
D.s.p. = Drying shrinkage expressed as per cent of plastic length.
F.s.d. = Fire shrinkage expressed as per cent of dry length.
F.s.p. = Fire shrinkage expressed as per cent of plastic length.
T.s.p. = Total shrinkage expressed as per cent of plastic length.

Significance of Tests. It should be borne in mind that the following tests are simply preliminary tests to indicate the general possibilities, and that any particular deposit must be carefully sampled and tested before any plans are made to develop the deposit commercially. This report is intended simply to indicate the most promising localities where clay or shale of economic value may be found in Michigan, and not to

[1]See Chapter IV, Physical Properties.
[2]Mich. Geol. Survey VIII, Part I (1900).

prove up any deposit for any purpose. Lack of good raw material is the most general cause of failure of Michigan brick and tile plants. This can be prevented only by careful sampling and testing of the deposit by a competent engineer.

The results of the following tests indicate that the shales of the Southern Peninsula are generally much better ceramic material than the surface clays. The cement companies are aware of this fact, but thus far the shale resources of the State are not generally recognized by the brick and tile manufacturers. The idea seems prevalent that Michigan has no shale and that the surface clays are the only possible raw material for brick. This is far from true.

Michigan's shale (Fig. 68) resources are adequate to supply the State with face brick, tile, sewer pipe, and similar products for an indefinite period. There are also many surface clay deposits of much smaller extent that may be used for all forms of building brick and tile. A steady demand for the better grades of building material exists practically throughout the State. Yet most of our face brick and building tile is shipped in from Ohio and even as far south as St. Louis, Mo. The clay face brick plants in Michigan operated continuously through the coal shortage of 1922, one plant paying as high as ten dollars a ton at the mines for coal. A properly designed and operated plant making high grade products from a good deposit of suitable shale or clay near any of the larger markets should prove a profitable undertaking.

On the Northern Peninsula there are extensive deep deposits of lake clay that may be used for all forms of building brick and tile. The older shales of this peninsula are generally unsatisfactory and must not be confused with the shales of the Southern Peninsula.

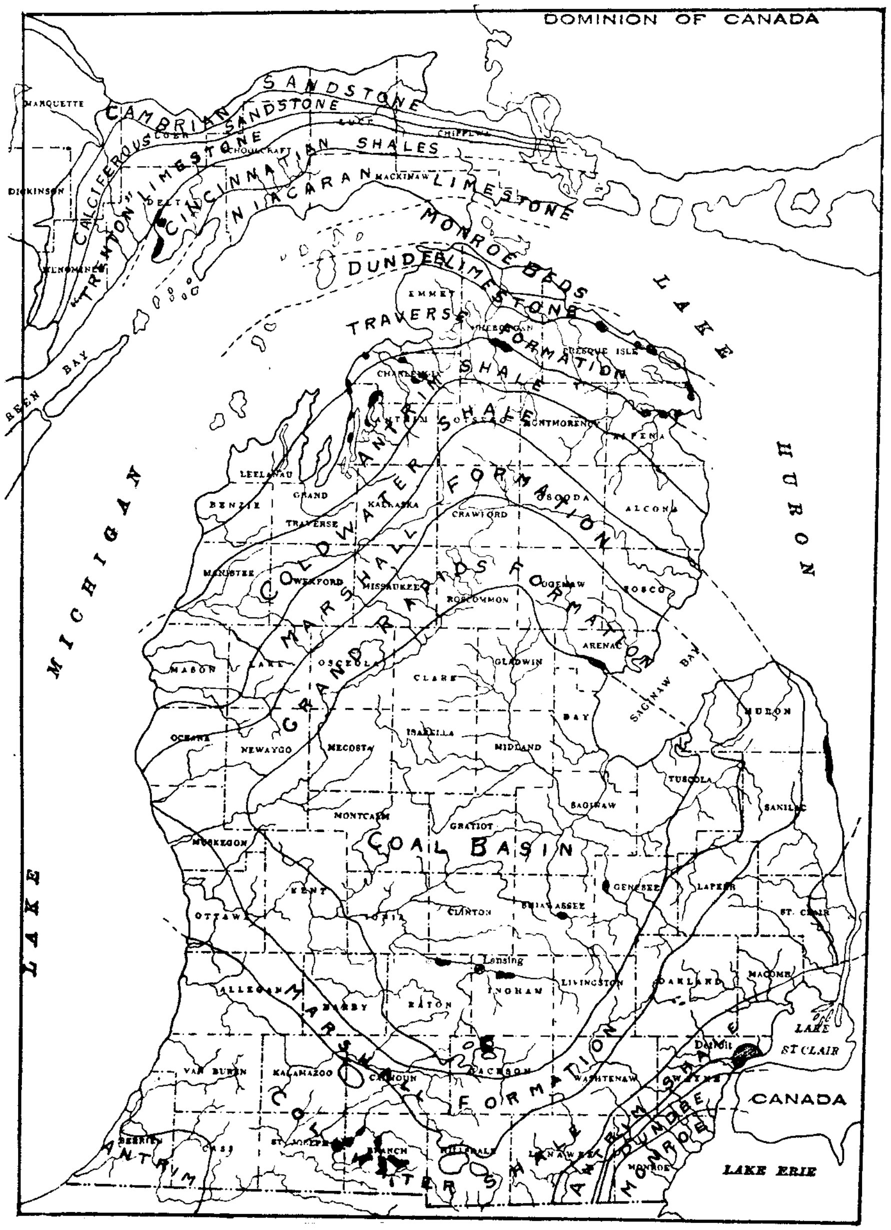


Figure 68.—Sketch map showing the distribution of hard rock formations and the areas (solid black) in which exposures of shale occur.

THE SOUTHERN PENINSULA

GENERAL DESCRIPTION

In the Southern Peninsula the glacial deposits are generally much thicker than in the Northern Peninsula, the average thickness of the drift being about 300 feet. In places near the border of Lake Michigan the drift is known to exceed 600 feet, and near Cadillac it is over 1200 feet. The drift of this peninsula, like that of the northern, is the product of at least two separate invasions. The amount of weathering and cementation of the older drift that occurred before the deposition of the younger is much greater than the surface weathering and alteration in the uppermost or youngest drift. The great difference in the hardness of the older and of the younger drift leads well drillers to apply the term "hardpan" to the older and harder deposits, and is evidence of the much greater interval of time elapsed between glaciations, than since the last.

The main body of drift in Michigan seems to have been deposited in the Illinoian and Wisconsin stages of glaciation. Most of the surface deposits were laid down by the Wisconsin glaciation, but frequently an older (Illinoian) till is found in cuts or cliffs, as near Avoca, St. Clair County; Fremont, Sanilac County; near Ypsilanti, Washtenaw County, and on the coast of Lake Huron on the east side of the "Thumb" and generally described as Pre-Wisconsin till.

The lake deposits in the Southern Peninsula are confined almost entirely to a strip 40 miles wide running up from the Ohio line north along the east side of the Peninsula to the "Thumb" and around Saginaw Bay into central Alcona County.

On the west side of the peninsula the glacial Lake Chicago covered a very narrow strip of the present shore about one to two miles or less except from Holland north across Ottawa and Muskegon counties, where it extended 10 to 25 miles beyond the limit of Lake Michigan and included the Delta of the old Grand River. In this area the old lake bed is almost entirely fine sand.

As it is to be expected from the history of the northern counties, the lake clays deposited in this district by the glacial Lake Algonquin are very similar to the lake clays in Mackinac, Luce and Chippewa Counties, which were deposited by the same lake.

The rock formations in the southern Peninsula all lie in a nearly horizontal plain with a gentle dip toward the center of the peninsula. The formations range in age from the upper part of the Silurian, through the Devonian to the Carboniferous, arranged like the piling up of plates in a series of diminishing size, and diminishing amount of dishing, from bottom to top. The uppermost and youngest formation, although resting on those that precede it in age, does not stand above some of their outlying parts. These formations are sedimentary marine deposits that have been pressed to their present compact condition by the weight of the overlying rock, and are practically free from any metamorphism.

Although the Pleistocene surface clays of the Southern Peninsula are probably less satisfactory than those of the Northern Peninsula, the many shales in the Devonian and Carboniderous Systems supply a wealth of material suitable for all kinds of heavy clay products.

The Bell shale, a soft blue shale usually about 50 to 80 feet thick, is the oldest number of the Traverse Formation, and outcrops in different places in Cheboygan and Presque Isle counties just above the Dundee limestone. The Bell shale is fine grained, plastic and seems to be suitable for brick and tile or possibly some pottery uses where a red burning clay is not objectionable.

The Antrim-Bedford shales of the Upper Devonian series are black at the bottom and generally blue at the top. They frequently contain concretions of siderite (iron carbonate) and pyrite (iron sulphide). When exposed to the weather the Antrim shale usually becomes very rusty due to its high iron content. The Antrim-Bedford shales vary from 150 to 575 feet in thickness and outcrop in many places through the northern counties where they form part of the bed rock, particularly in Antrim and Charlevoix Counties. The lower shale is bituminous and therefore must be carefully oxidized in burning. Both shales will burn to a hard red product suitable for all kinds of brick and tile. They may also be used as a raw material for Portland cement.

The Coldwater shales of the Lower Mississippian series are blue and gray shales with large concretions of siderite and lenses of sandstone known locally as "kidney rock" particularly near the top. In the western part of the State streaks of limestone and calcareous shale are common. The shale is 700 to 1000 feet thick and underlain in many places by the black Sunbury shale. The Coldwater shales are used as a raw material for Portland cement, but are not now used in making brick and tile although very suitable for that purpose.

The Coal Measure Shales are variable containing many different beds. but practically all of the beds are suitable for brick, tile and similar products where found in sufficient quantities.

The white shale ("fire-clay") of the Saginaw formation occurring with or without the coal seams in the Coal Measures is a semi-refractory clay, and suitable material for making all kinds of vitrified ware such as sewer pipe and paving brick.

The surface boulder or morainic clays in the central and north central parts of the Southern Peninsula do not as a rule contain excessive amounts of lime pebbles although they may be very stoney. The clays in the southern part of the state are very likely to contain large amounts of lime pebbles and are then practically useless.

In some areas that have been washed by the glacial lakes, lake clay of varying thickness may have been deposited. Some of these lake deposits contain very good brick or tile clay, particularly in the upper part of the deposit where the lime has been leached out and the clay is red burning; but these deposits generally run to lime concretions at depths of 3 to 12 feet and cannot be generally recommended. These deposits are also very variable as is evidenced by lake clays in Monroe, Wayne and Macomb Counties. The clays northwest of Lake Saint Clair are thoroughly leached and are very suitable for red brick to a depth of three feet, where lime concretions are found. In the Detroit district the lime concretions are not generally found above a depth of nine to twelve feet. Northwest of Lake Erie the clays may be good locally to a depth of three feet or they may contain lime pebbles from the very top.

River silts may be found in various parts of the state and in many places are suitable for common brick or tile.

At Harrietta, Wexford County, and near Harbor Springs, Emmet County, are deposits of a fine grained calcareous clay that, when properly prepared, seem as serviceable as Florida Fuller's Earth for clarifying oils.

Other special uses of Michigan clays may be developed by special study, but the surface clays of the Southern Peninsula are not generally to be recommended for ceramic materials. The shales found on the Southern Peninsula are generally far superior to the surface clays.

ALCONA COUNTY

The bed rock of the county is largely shale. Upper Devonian Antrim shale underlies the northeast corner of the county. The Coldwater (Lower Mississippian) shales run diagonally NW-SE in a belt about 20 miles wide, across the county.

In drilling for water on the eastern shore of Hubbard Lake it is reported that 164 feet of blue (Antrim) shale were penetrated without any show of water.

The surface soil is largely landlaid moraine and sandy drift, with some bowlder clay areas. A lake deposit of clay from 6 to 60 feet thick extends from about 5 miles north of Harrisville south to the county line and about 3 to 8 miles in shore. The same clay is probably found in or under the AuSable delta to the southwest. The upper part of the deposit is red and the lower part blue clay. The latter is very heavy, ropey clay and is found at a depth of 20 feet at Mikado. About one or two miles north of Mikado the clay is thickest, about 60 feet.

A number of years ago the upper red clay at Mikado was used for the manufacture of common brick. Considerable trouble was caused by lime pebbles, which are found in small local areas scattered through the deposit, and the workings were abandoned.

About three miles southeast of Harrisville in sections 21 and 22, (T. 26 N., R. 9 E.) good red brick was made by the soft mud process about 1887.

Clay from Section 24, T. 25 N., R. 8 E., three miles south of Mikado, along the east bank of the creek has been used in Oscoda for setting brick in furnaces. But no clay possessing the necessary refractory properties to warrant its use for such purposes in modern practice could be found.

A sample of clay (166) from section 11, T. 25 N., R. 8 E., one mile south of Mikado and of the same general type as occurs through this deposit seems to be fair material for brick or tile.

Burning Test

Sample No. 166. Field Sheet No. 186.
Section 11, T. 25 N., R. 8 E.
Plasticity .315 gm. water per gm. clay.
Average linear drying shrinkage 11.7 per cent.
Average tensile strength about 116 lbs. per sq. in.
Apparent Sp. Gr. dry 2.67.

Cone No.	Cone Temp. °C.	Porosity.	Linear Shrinkage.	Apparent Sp. Gr.	Hardness.	Color.
010	950	.392	3.7%	2.74	Soft burned	Salmon
08	990	.402	3.0	2.70	Soft burned	Cream
06	1,030	.404	2.0	2.70	Soft burned	Cream
04	1,070	.422	3.2	2.83	Soft burned	Cream
02	1,110	.405	4.8	2.84	Soft burned	Cream
1	1,150	.266	9.9	2.74	Hard burned	Light olive
3	1,190	.190	13.5	2.84	Hard burned	Light olive
5	1,230	.022	15.7	2.48	Vitrified	Olive
7	1,270	.032	15.3	2.46	Vitrified	Olive
9	1,310	....	....	....	Viscous.	

Reddish brown clay. Easily molded.
Burned by H. W. Jackman.

ALLEGAN COUNTY

The Tyler Brothers made brick and tile at Saugatuck, Section 9, T. 3 N., R. 16 W., from a lake clay. They ceased operations in 1910 and the auger machine was later moved to Hamilton and is used by the Zeeland Brick Company.

This company has a plant about one mile south of Hamilton on the Allegan Road and the Pere Marquette Railroad in NW¼ section 8, T. 3 N., R. 14 W. The company owns a quarter section including about 50-60 acres of red lake clay. The plant is equipped with a steam shovel, skip cars, an auger machine with twin die for brick, dies for drain and building tile, and a steam heated intermittent drier.

Some brick is burned in oil fired scove kilns, but most of the product is burned in round downdraft kilns, 30 feet in diameter. The plant is equipped with six of these kilns and has a daily capacity of about 40,000 brick. Anthracite coal is added to the clay in the pug mill to aid in burning the brick to a good hard burned, dense product.

The clay is a red lake clay about 10 feet thick, covered by sand, which is used in tempering. The following test indicates that the sample is good material for brick or tile:

Burning Test

Sample No. 25. Field Sheet No. 24.
Section 8 NW¼, T. 3 N., R. 14 W.
Plasticity .327 gm. water per gm. clay.
Average linear drying shrinkage 11.4 per cent.
Average tensile strength about 137 lbs. per sq. in.

Cone No.	Cone Temp. °C.	Porosity.	Linear Shrinkage.	Hardness.	Color.
08	990	.382	0.7%	Soft burned	Salmon
06	1,030	.370	1.1	Soft burned	Salmon
04	1,070	.349	1.9	Soft burned	Salmon
02	1,110	.190	9.5	Hard burned	Light red
1	1,150	.019	11.8	Vitrified	Dark brown
3	1,190	.025	8.3	Vitrified	Dark gray brown
5	1,230	....	....	Melted	

Molded easily. Suitable for brick and tile.

The Allegan Brick Company is operated by the Cadys, father and son, without other labor. The plant is just west of the road at the southwest corner of Allegan, about the center of Section 32, T. 2 N., R. 13 W. The clay (sample 24) is a river deposit about 5 to 6 feet deep. There is about one acre of this red clay left and another deposit of 10 acres near by. The clay is wheeled in from the pit, a distance of over 400 feet, on wheelbarrows, and molded in a six brick soft mud machine with vertical pugmill. The pugmill and molding machine is direct driven by a horse walking around above the machine on the charging platform. The brick is dried in open drying racks and burned in wood fired scove kilns. A fairly good quality red brick is produced and sold locally. This plant is probably the most primitive of any plant in Michigan, at least so far as its power is concerned. The following burning test indicates that the sample of clay from this deposit could be used to make a higher grade product than soft mud common brick. It has a burning range of 10 cones, with uniform shrinkage, and could be used for hard burned front brick or tile, or possibly some vitrified products.

Burning Test

Sample No. 24. Field Sheet No. 23.
Section 32, T. 2 N., R. 13 W.
Plasticity .264 gm. water per gm. clay.
Average linear drying shrinkage 4.9 per cent.
Average tensile strength about 70 lbs. per sq. in.

Cone No.	Cone Temp. °C.	Perosity.	Linear Shrinkage.	Hardness.	Color.
06	1,030	.331	0.9 %	Soft burned.....	Salmon
04	1,070	.298	2.3	Soft burned.....	Light red
02	1,110	.202	6.0	Hard burned....	Deep red
1	1,150	.088	9.6	Hard burned....	Chocolate brown
3	1,190	.040	9.7	Hard burned ...	Chocolate
5	1,230	.045	7.0	Vitrified........	Chocolate
7	1,270	.028	6.0	Vitrified........	Chocolate
9	1,310	.038	2.3	Vitrified........	Dark chocolate

Molded easily and seems suitable for face brick and tile.
Burned by H. W. Jackman.

Northwest of Otsego on the southwest side of the Lake Shore and Michigan Southern Railroad, in Sections 9 and 10, T. 1 N., R. 12 W., there is a deposit of boulder clay on the property of the Cushman Brothers. Before the Civil War this clay was shipped and also used by the railroad, presumably for patching the fire boxes in the old wood burners. The old pit from which the clay was formerly obtained is now a small pond near the northern end of the deposit. At the request of the present owners this deposit was visited and tested. The following is taken from the report of this investigation:*

"The deposit was visited and drilled to determine the thickness and extent of the clay bed, and to obtain representative samples for testing. These samples were burned to determine the burning properties, and analyzed to determine the value of the clay as a raw material for Portland cement.

[1]Report No. 202 of Clay Deposit of C. C. Cushman. Dept. of Eng. Research, University of Michigan.

Sample No. 201 is from the upper ten feet of the deposit (reddish blue clay).

Sample No. 202 is from the lower twenty feet of the deposit (blue clay).

Drilling indicates that the deposit extends for at least 300 yards in a north and south direction and about 100 yards east and west and is approximately 28 feet thick.

Burning Test

Sample No. 201. Field Sheet No. 209.
Sample No. 201. Field Sheet No. 209.
Sections 9-10, T. 1 N., R. 12 W.
Plasticity .263 gm. water per gm. clay.
Average linear drying shrinkage 7.2 per cent.
Average tensile strength about 95 lbs. per sq. in.

Cone No.	Thermocouple Temp. °C.	Porosity.	Linear Shrinkage.	Hardness.	Color.
010	916	.404	0.0 %	Softer than steel...	Salmon
08	950	.448	1.2	Softer than steel...	Salmon
06	1,000	.468	2.2	Softer than steel...	Salmon
04	1,040	.445	3.5	Harder than steel..	Salmon
02	1,120	.309	5.5	Harder than steel..	Salmon
1	1,175	.181	10.8	Harder than steel..	Brown
3	1,220	.016	15.8	Vitrified..........	Dark brown
5	.....	....	....	Viscous (melting)	

Suitable for brick and tile.
Burned by Mark Huck.

Burning Test.

Sample No. 202. Field Sheet No. 209.
Section 9-10, T. 1 N., R. 12 W., Allegan County.
Plasticity .294 gm. water per gm. clay.
Average linear drying shrinkage 8.2 per cent.
Average tensile strength about 75 lbs. per sq. in.

Cone No.	Thermocouple Temp. °C.	Porosity.	Linear Shrinkage.	Hardness.	Color.
010	916	.400	0.6 %	Soft burned.....	Salmon
08	950	....	0.8	Soft burned.....	Salmon
06	1,000	.462	1.6	Soft burned.....	Salmon
04	1,050	.375	4.0	Soft burned.....	Salmon
02	1,120	.299	5.0	Hard burned....	Light brown
1	1,175	.043	8.8	Vitrified........	Dark gray brown
3	1,220	.015	11.4	Vitrified........	Chocolate brown
5	.....	....	....	Viscous	

Suitable for brick and tile.
Burned by Mark Huck.

Chemical Analysis

Sample No. 201. Field Sheet No. 209.
Sections 9-10, T. 1 N., R. 12 W., Allegan County.

			Av.
Loss on Ignition	14.08	14.10	14.09
Silica SiO_2	50.72	50.55	50.64
Alumina Al_2O_3	16.03	15.90	15.96
Titania TiO_2	0.32	0.32	0.32
Lime CaO	8.56	8.49	8.53
Magnesia MgO	4.95	4.99	4.97
Iron Fe_2O_3	2.60	2.53	2.56
Alkalies Na_2O+K_2O	4.12	4.02	4.06
			101.13

$$\frac{SiO_2}{R_2O_3}=\frac{50.64}{18.52}=2.7$$

There are probably about 500,000 to 750,000 cubic yards of clay in the deposit which can be used for the manufacture of brick and tile."

ALPENA COUNTY

In the northern half of Alpena County the Traverse limestones and shales outcrop in many places near the shore of Lake Huron. The Antrim shale underlies the southern and southwestern portions of the county. It is exposed at several places from Partdridge Point west-northwest to and beyond Paxton.

The Antrim shale is quarried in sec. 30, T. 31 N., R. 7 E. on the D. & M. Railroad near Paxton about one-half mile east of Apple Orchard by the Huron Portland Cement Company. The shale is black in the upper strata except where discolored or rusted by weathering, and runs to bluish black shale in the lower strata. The shale contains dark purple and yellow concretions of pyrite and large concretions of lime-iron carbonate. The quarrying is done by drilling the bench, blasting, and loading the railroad cars by a steam shovel in the same manner as employed at Ellsworth. The shale is shipped to the plant in the eastern part of Alpena on the D. & M. Railroad. The following analyses of the different levels in the quarry were furnished by Mr. W. M. Smith, chief chemist of the Huron Portland Cement Company.

	Blue Black Low Level. %	Rusty Upper. %	Upper 5 Ft. %
Volatile	17.40	11.86	11.76
Silica (SiO_2)	54.52	62.32	60.22
Alumina (Al_2O_3)	13.46	16.48	14.44
Iron (Fe_2O_3)	5.12	4.44	7.60
Lime (CaO)	2.22	2.34	1.52
Magnesia (MgO)	2.15	2.33	2.20
Sulphur (S as SO_3)	2.50	2.04	2.21
K_2O	....	....	1.30
Na_2O	....	....	1.05
TiO_2	....	....	0.95

Burning Test

Sample No. 134. Field Sheet No. 144.
Section 30, (center), T. 31 N., R. 7 E.
Mixed sample of Antrim shale from quarry of the Huron Portland Cement Co.
Plasticity .282 gm. water per gm. clay.
Average linear drying shrinkage 5.7 per cent.
Heated for 5 hours to burn out carbon.

Cone No.	Cone Temp. °C.	Porosity.	Linear Drying Shrinkage.	Hardness.	Color.
08	990	.389	2.6%	Soft burned	Light red
06	1,030	.359	4.0	Soft burned	Light red
04	1,070	.298	6.6	Hard burned	Red brown
02	1,110	.101	12.2	Hard burned	Chocolate
1	1,150	.118	12.7	Vitrified	Chocolate
3	1,190	.040	7.6	Vitrified	Dark chocolate
5	1,230	.056	−1.9	Vitrified	Dark chocolate
7	1,270	.146	−6.2	Vitrified	Dark chocolate

Last four samples cracked somewhat in cooling.
Burned by H. W. Jackman.

The shale is good material for brick and tile and will make a good dark brown or chocolate face brick. It should be ground in a wet pan or treated to develop its plasticity, and burned carefully. It is also good material for Portland cement and is preferred by the Huron Cement Company to the clay or shale of the Bell or lowest member of the Traverse Formation which was formerly used.

The latter is somewhat pebbly blue clay obtained from section 18, T. 32 N., R. 9 E., east of Middle Lake, near the shore of Lake Huron, and shipped to their plant at Alpena. This clay has been analyzed as follows:

	I	II	III
	%	%	%
Volatile	7.69	5.13	....
SiO_2	56.17	61.09	57.96
Al_2O_3	17.23	19.19	20.44
Fe_2O_3	5.18	6.78	3.03
$CaCO_3$	6.03	....	9.12
CaO	....	2.51	.28
$MgCO_3$	2.62	....	5.02
MgO	....	.65	....
K_2O	....	1.8	3.40
Na_2O	....	1.36	
SO_3	.27	1.42	.72

I. W. M. Smith, Huron Portland Cement Company.
II. Ries, Michigan Geological Survey VIII, Pt. I, p. 48, analysis 17.
III. S. H. Ludlow, Alpena Portland Cement Co., I. C. Russell, Portland Cement Industry in Michigan, U. S. Geological Survey, 1902, page 665.

I. C. Russell* also includes as analyses of this clay, two analyses of the Antrim shale near E. Jordan and Chestonia given by Ries.** This is obviously an error.

At Rockport about 2½ miles north of this old clay pit is the quarry of the Great Lakes Stone & Lime Company. The limestone is about 40 feet thick and belongs to the Long Lake series. The Bell shale directly underlies the limestone, and in this region appears to be about 50 feet thick. The shale is blue, very soft, and weathers to clay readily. It contains two or more thin limestone beds, one of which is about 6 or 8 feet below the top. This shale, reported by W. M. Smith, analyzed as follows:

	%
Silica (SiO_2)	38.48
Alumina (Al_2O_3)	14.04
Iron (Fe_2O_3)	5.0
Lime (CaO)	16.26
Magnesia (MgO)	2.6

With the exception of the high lime content this analysis is generally similar to the analyses of the clay in the cement company's old pit. This clay-shale at Rockport is similar to the clay found in the limestone at Petoskey, Emmet County, Charlevoix, Charlevoix County, and south of Bell, Presque Isle County. The shale or clay at the surface two and one-half miles south of Rockport is apparently an exposure of the lower Bell shale.

Some of the shales of the Upper Traverse or Thunder Bay series are markedly different from the Bell shale, but most of them are calcareous and are known to drillers as "soap rock." The Upper Traverse Shales are exposed in several places. Ries reported a deposit of a weathered shale at the end of Third Street in Alpena. A ten foot bed of shale is exposed along a prominent rock terrace on the south side of Thunder Bay River on the line between sections 17 and 18, T. 31 N., R. 8 E., and an 8 foot bed of blue fossile calcareous shale on the north side of the river in section 8. Thinner beds of shale are exposed in the southwest part of Alpena, at Fletcher dam, and near Orchard Hill. On the Potter farm in section 20, T. 31 N., R 8 E. the rock section includes a 19 foot bed of blue fossiliferous shale. At the Upper or Four Mile dam there are 12 feet of shale-clay underlain by three feet of hard calcareous blue shale.

Ries reported that the smooth, unctuous clay at the end of Third Street, Alpena, effervesced freely with acid and was "too calcareous for many uses." It was noted that the clay appeared to come from under a limestone and to have been a calcareous shale which had slacked in weathering. The main stratum is of thick, heavy, gummy blue clay (sample 133) and was formerly used to make brick. The plant was completely destroyed some years ago, apparently by fire. The product was a cream brick with slight red tint.

*loc. cit.
**loc. cit., p. 46, Nos. 14, 15.