Layman[1] have suggested a preliminary heat treatment of the clay to reduce the plasticity and drying shrinkage. It is suggested that the clay be heated in rotary kilns and the treatment be carried just far enough to overcome the molding and drying troubles. The effect of the heating is a function of time as well as temperature; 200°C is high enough for some clays but others must be heated to a red heat. The amount of heating must be carefully controlled to be effective and yet not destroy the plastic qualities of the material.[2] In addition to the improvement in the drying and burning properties of the clay, this drying of the clay makes grinding and screening much easier, and is in many cases well worth while from this standpoint alone.

Tempering. Tempering consists in mixing the clay with the proper amount of water for molding. This was formerly done in ring pits 20 to 25 feet in diameter and about 3 feet deep in which a six foot iron wheel revolved in a spiral path. One pit held enough clay for 20,000 to 30,000 brick, which was tempered in five to six hours. The old-fashioned primitive foot tramping still persists only in the manufacture of glass pots and special pottery.

Pug mills and wet grinding are the two mechanical methods available for tempering clays. Pug mills (Plate XI) are generally used for tempering. They consist of semi-cylindrical troughs from 3 to 20 feet long containing one or two horizontal shafts bearing knives set spirally around them with varying pitch. Clay and water are charged at one end, thoroughly mixed and pushed out at the other end by the action of the blades. Pug mills exert absolutely no grinding action and do not tend to develop the plastic qualities as does wet grinding. Where the clay is soft and of sufficient plasticity without special treatment, as is generally the case with the surface deposits of Michigan, pug mills are found to be the cheapest mechanical means of mixing and tempering clays. In working Michigan surface clays, the combination of wet grinding rolls followed by pug mills for tempering, is almost universal practice in brick and tile plants.

The use of the wet pan as a preliminary grinder of crude clay has been briefly discussed. When used as a tempering machine, with grinding incidental, the construction is slightly different and the operation differs considerably. The face of the mullers varies from 3 to 8 inches instead of 10 to 20 inches as when used for wet grinding. The crushing action is emphasized in the wider wheels, and the cutting and mixing in the narrow wheels. The mullers are usually of about the same weight, which is obtained by large hubs. The scrapers are designed more to stir

[1]Trans. Am. Cer. Soc. XI, p. 354, p. 392 (1909).
Ibid, XII, p. 504 (1910).
[2]G. H. Brown & Montgomery, Trans. Am. Cer. Soc. XIV, p. 709 (1912).
Ed. Orton, Jr. Trans. Am. Cer. Soc. XIII, p. 765 (1911).

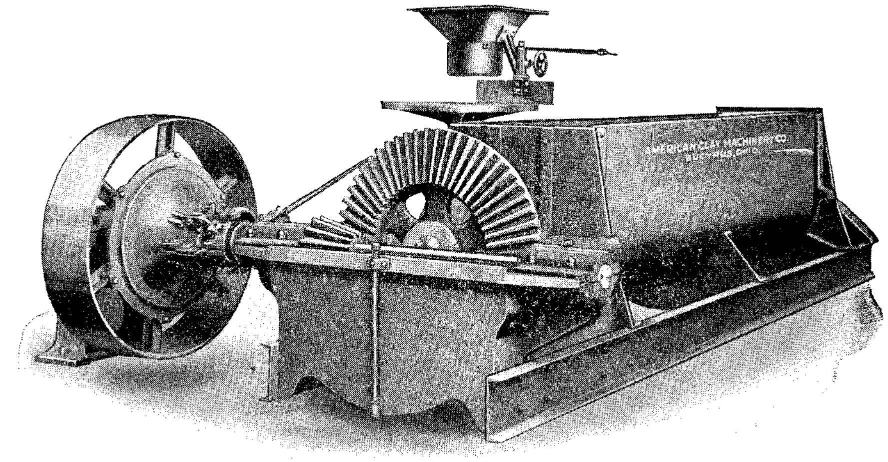

Plate XI, Figure 1.—Pug mill equipped with disk clay feeder.

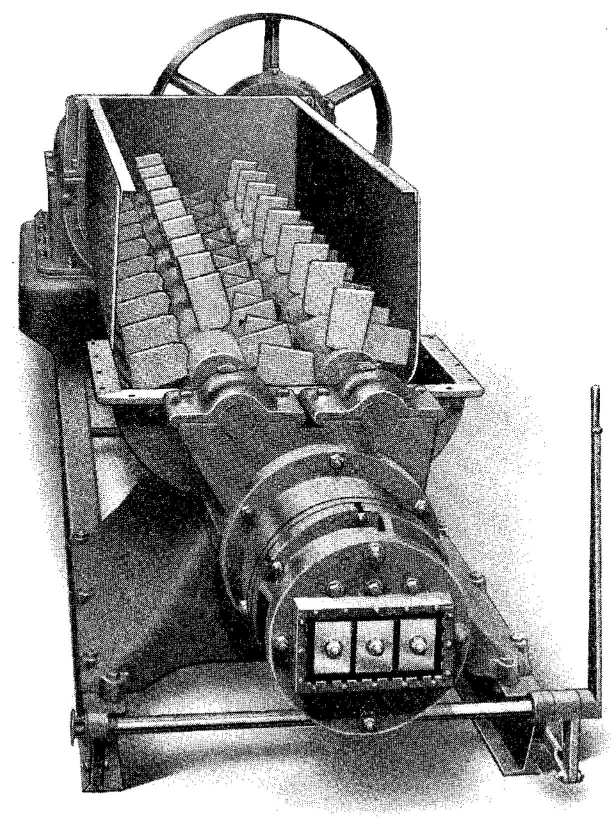

Plate XI, Figure 2.—Large pug mill in section showing knives on two shafts, combined with auger extrusion machine. Capacity 3,000 to 7,000 brick per hour with 75-100 H. P. (Cuts by Hadfield-Penfield Steel Co.)

and mix the clay than to simply direct it under the mullers as is the case when used for grinding.

The pan is placed under the ground clay bin which is equipped with a spout so that the clay may be easily introduced into the pan. The pan being run empty, the valve in this spout is opened at the same time as the water valve. In about ten or twenty seconds the stream of clay is stopped but the water is continued until the clay becomes too soft and sticky to use. As the grinding continues this water is rapidly taken up by the clay and more must be added from time to time. In about two to four minutes the clay is properly tempered as determined by touch or feel, and is removed as rapidly as possible from the pan to an elevator or other conveyor. Although automatic unloaders of many types have been used with entire success, the hand method of using a long handled shovel pivoted to the frame is still in general use.

The wet pan gives the most thorough tempering possible. The grinding action is important, particularly with hard gritty clays, and in mixing two or more clays. Frequently the long aging period to soften the clay following pugging may be entirely eliminated by the use of wet pans. While the advantages of the wet pan over the pug mill are important, it possesses several serious disadvantages. Its cost of installation is generally about twice that of a pug mill; its power consumption is high; and the intermittent nature of the process makes for a variable product.

Aging. Aging consists in storing the tempered clay in damp cellars or bins in which the clay is kept covered with wet cloths for periods ranging from a few days to many months. When the clay is to be aged, it is usually tempered with warm or hot water in a pug mill. The aging process softens the clay, making it more uniform, with greater plasticity, and tougher or stronger. The increase in plasticity is frequently explained as due to the growth of algae[1] and the other improvements in physical properties as due to better distribution of the water and slaking of the clay.

Wedging. Hand wedging consists in cutting a large lump of clay as it comes from the pug mill into two pieces, bringing the two parts together forcibly, and kneading the united lumps. This action is repeated a number of times to make the clay homogenous and free from air bubbles, as the action of the pug mill tends to separate the mineral constituents and gives an uneven distribution of occluded air which expands when the pressure is reduced or the ware heated causing rupture.[2] Manual tempering by this or similar methods is used only in maufacturing pottery or special high grade products.

Molding. Molding, or forming the clay to make the desired product, is done in a number of ways. Bricks are formed by the soft mud, stiff

[1]H. Spurrier, J. Am. Cer. Soc. IV, p. 113 (1921), "The Why of Clay Aging."
[2]H. Spurrier, J. Am. Cer. Soc., I, p. 710 (1918) and III, p. 388 (1920).

mud, or dry press processes. Drain tile, building tile, sewer pipe, and similar products are formed by the stiff mud process. Pottery products are thrown on a potter's wheel, formed on a jolly or jig, pressed in molds, or cast. Bricks and roofing tile may be formed by the stiff mud process followed by repressing.

Soft Mud Molding. In soft-mud molding, the clay or clay and sand mixture is tempered to the consistency of a soft mud and is pressed into wooden molds. As the wet clay is sticky, the molds are sanded before the clay is pressed in the molds to prevent the clay from sticking to the mold. For this reason soft mud bricks show five sanded surfaces with the sixth surface somewhat rough, where the excess clay has been "struck off" even with the top of the mold. This process was the first method of molding employed, and is still widely used. The earlier practice of hand molding has been replaced entirely in this country by machines except for special products such as fire brick.

The soft mud molding machine (Plate XII, Fig. 23) consists of an upright box, that sometimes contains a vertical pug mill in the smaller machines. The soft mud from the pug mill is pushed into the press box by the pug mill. In the modern machines, this press box is outside (Plate XIII) to avoid trapping of air. The sanded molds are shoved underneath the press box from the rear of the machine, the plunger descends and forces the clay into the molds. The filled mold is then pushed forward onto the delivery table by the empty one which replaces it under the press box. The excess clay on top of the mold is "struck off" by an iron scraper and the mold emptied by inverting on a pallet. The mold is then sanded with dry sand and returned to the rear of the machine. The pallet carrying the six, seven, or nine brick from the mold is sent to the drier. Under good conditions a soft mud seven brick machine has a capacity of 25,000 to 45,000 brick a day.

This method of molding is adaptable to a wider range of clays than any of the other methods, and is capable of producing a homogeneous brick not affected by frost. If the clay is plastic and requires a large amount of water to reduce it to the consistency of a soft mud the drying shrinkage will be excessive and the brick will crack in drying. In order to reduce the drying shrinkage, sand is mixed with the clay. For this reason sandy clays of low plasticity are preferred for the soft mud method of molding.

The molding machines are made more or less automatic, but even at best the operating of a soft mud machine is exacting and monotonous work. The dumping of the molds onto the pallets is the "neck of the bottle" so far as the capacity of the machine is concerned. A seven brick machine with hand dump operated by a full crew of three men will produce about 35,000 a day. If the same machine is equipped with an

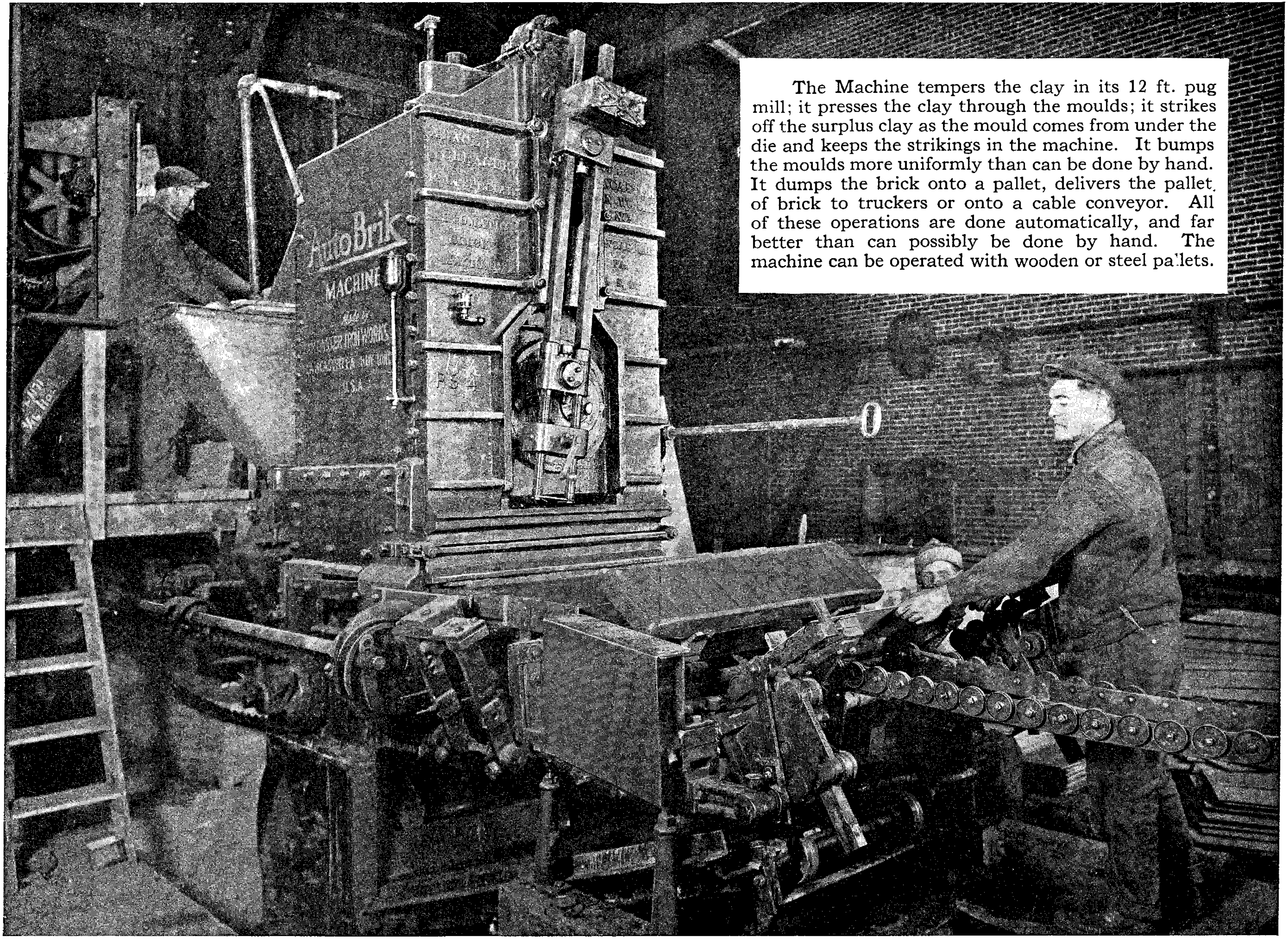

Plate XII.—Automatic soft mud molding machine.
(From Lancaster Iron Works.)

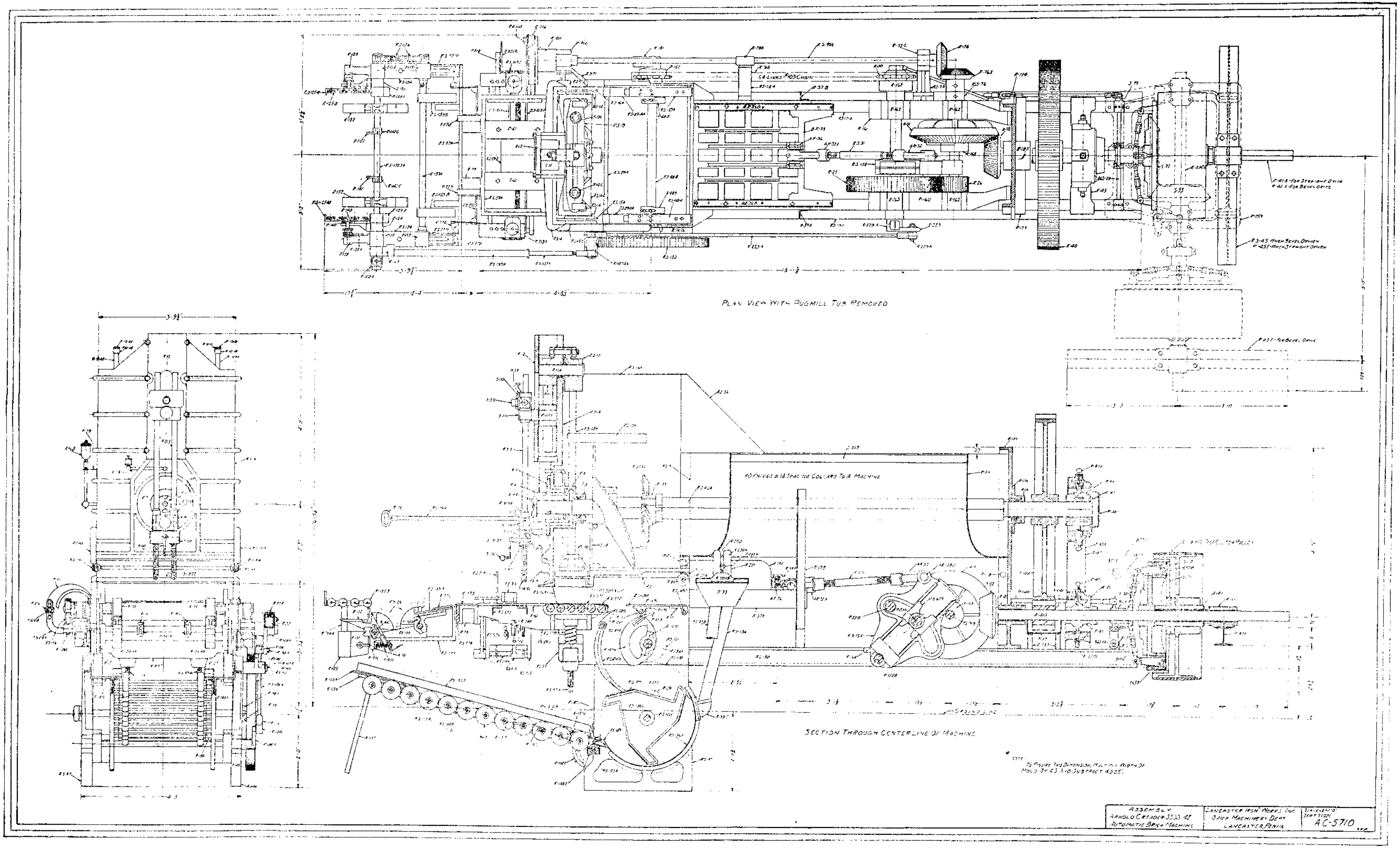

Figure 23.—Automatic soft mud brick molding machine. (Cut by Lancaster Iron Works.)

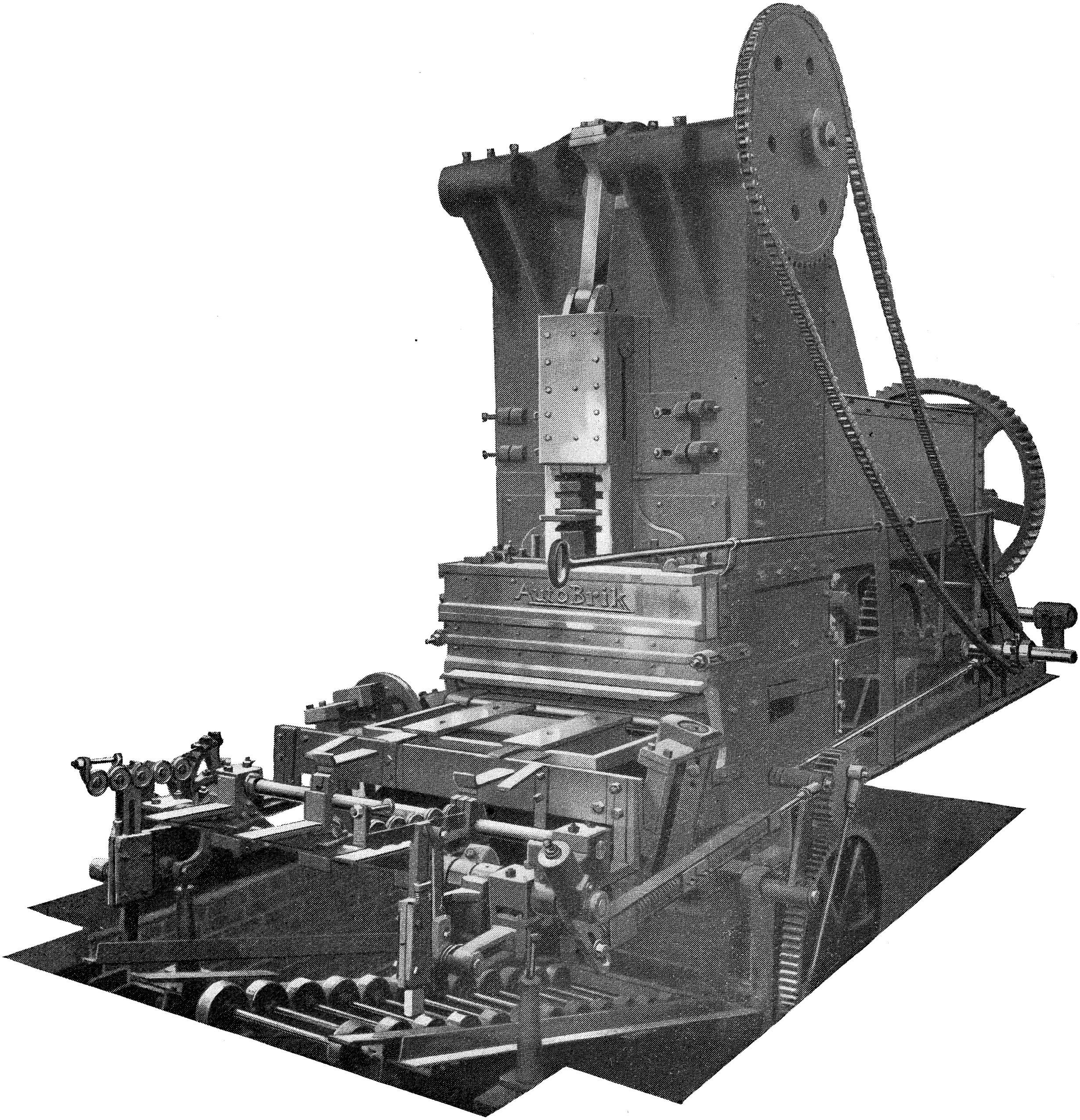

Plate XIII.—Automatic soft mud molding machine with outside press box.
(From Lancaster Iron Works.)

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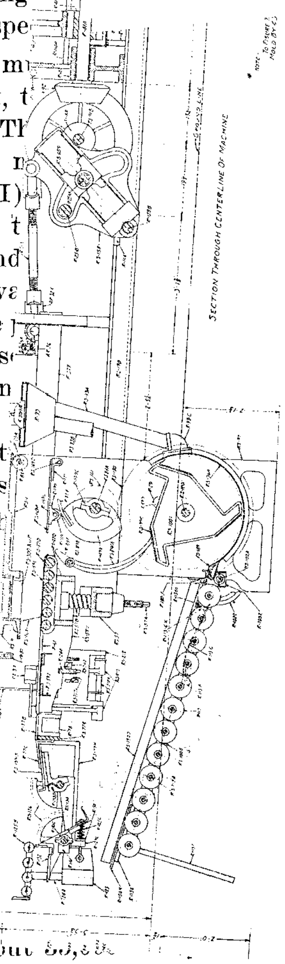

Figure 23.—Automatic soft mud brick molding machine. (Cut by Lancaster Iron Works.)

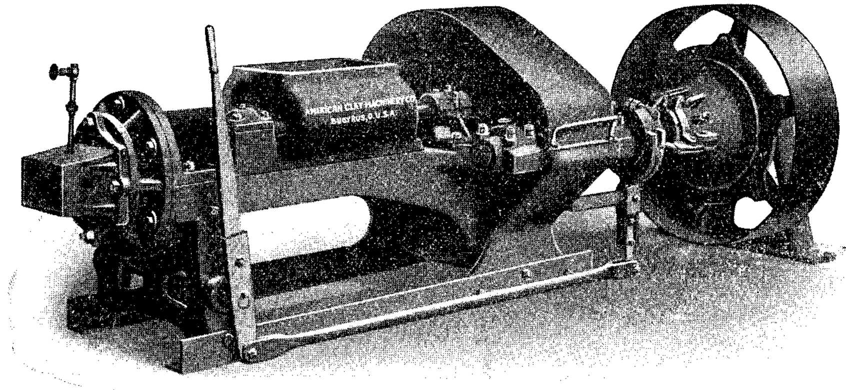

Plate XIV, Figure 1.—Auger extrusion machine.

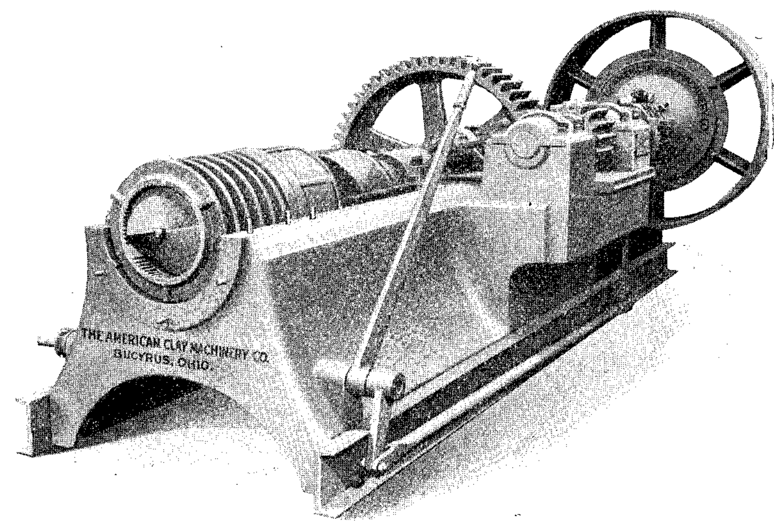

Plate XIV, Figure 2.—Internal mechanism auger extrusion machine.

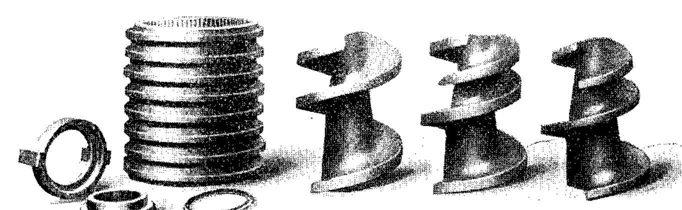

Plate XIV, Figure 3.—Auger screws and liners used in auger machine. (Cuts from Hadfield-Penfield Steel Co.)

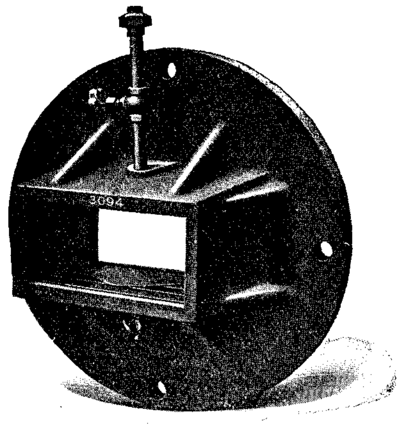

Plate XV, Figure 1.—Extrusion die for brick (side cut brick).

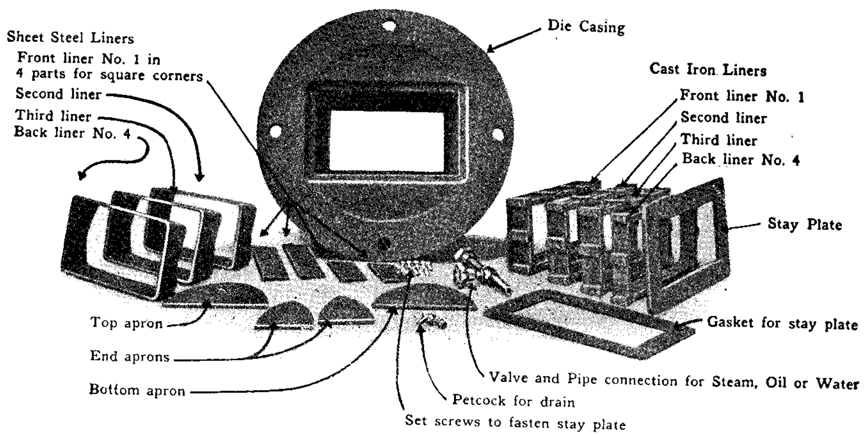

Plate XV, Figure 2.—Parts of brick extrusion die (American Neidergesaess Die). The connecting pipe with valve, shown in the cut, may either lead to the boiler or a water tank, or to an oil reservoir. On the right are shown four cast-iron liners having channels around their edges. These liners fit into the die casing. On the left are shown the sheet steel liners which fit into each cast-iron liner. The front four sheet steel liners fit into the front cast-iron liners and make the sharp corners on the brick. When round corners are desired on the brick these are replaced by a liner similar to the second liner. The four round edged plates in the foreground are termed the aprons, and are put in last over all the liners. The whole is held in the die casting by the stay plate. Proper packing, cement or putty, is used to prevent leakage. The duties of the aprons are two-fold: to prevent wearing of the liners and to exclude the lubricant where not wanted so as to insure an even flow.

automatic dump the production is increased to over 45,000. About the same production can be obtained by putting a double crew on the hand dump.

Stiff Mud Molding. In the stiff mud process the clay is tempered with less water, so that it is much stiffer, being plastic, and not sticky. In this condition the clay is forced through a die of the desired form and the issuing bar or stream of clay cut to the desired length. The most common type of stiff mud machine used for extruding brick and tile is the auger machine (Plate XIV). In general the form of this machine is that of a horizontal cylinder closed at one end, with the opposite end tapering off into a die of the desired shape. In the cylinder is a shaft carrying blades similar to those of a pug mill and a tapering screw or propeller at the end nearest the die. For best results the die must be adapted to the clay and placed at the proper distance from the auger screw. The die is often heated by steam or lubricated by oil on its inner side to facilitate the flow of clay (Plate XV), but lubrication is of less importance than the lines of the die and the preparation and tempering of the clay.*

The tempered clay is charged into the cylinder at the end farthest from the die, is mixed and pushed forward by the revolving blades until it is seized by the screw and pushed through the die. This action compresses the clay, and with the friction between the clay and the die tends to make the center of the issuing clay stream move faster than the outer portion, particularly the corners. The differential velocities within the clay stream and the action of the screw at the end of the shaft tend to produce a laminated structure in the extruded brick which is generally most pronounced in highly plastic clays which take a high polish, but may be very noticeable in moderately plastic clays if the machine is not properly adjusted. If the friction between the clay and the surface of the die is excessive the clay stream will be torn along the edges, producing serrations similar to the teeth of a rip saw. If the clay is too soft it will tear at the corners and if too dry it will crack.

The critical features of the auger machine are the auger which forces the clay through the die, and the die. The front end of the shaft is fitted with a casting having a spiral thread of large pitch, making one or more complete turns around the core or axis. This casting is called the auger. It is designed to gather the clay delivered to it by the segmental screw composed of the knives and blades farther back on the shaft, and compress and push the clay forward through the die. If the auger is made of a single spiral, a spacer or collecting chamber must be allowed between the end of the auger and the back of the die. Otherwise the

[1]G. Simcoe, Trans. Am. Cer. Soc. XI, p. 343 (1909).
W. H. Artz, Trans. Am. Cer. Soc. XI, p. 411 (1909).
H. Spurrier, J. Am. Cer. Soc. 3, p. 388 (1920).
J. J. F. Brand, J. Am. Cer. Soc. 5, p. 355 (1922).

clay coming from the auger in a single stream which follows the turns of the auger about the die entrance exerts an uneven pressure on opposite sides of the die, causing the flow of the column of clay issuing from the die to be irregular and wabble or lunge from side to side as the opening of the auger passed from one side to the other. The spacer or collecting chamber absorbs partially or completely this irregular pressure.

Where laminations cannot be tolerated, augers with two threads, or "double bitted," are usually satisfactory with the intervention of a collecting chamber. The clay being delivered in two opposite streams, there is no tendency for the clay column to wabble and much less tendency to develop laminations. The length of the spacer, or the distance between the end of the auger and the die is of great importance and can be determined only by experiment. The correct distance is noticed, when found, by a greatly improved structure of the bar. Frequently a better product can be formed by changing the direction of clay stream as when employing a vertical pug mill and horizontal extrusion press.

In extruding thin shapes such as floor tile, triple thread augers are necessary and in some cases augers with four threads are used. The state brick plant at Onondaga uses a four thread auger with carefully adjusted spacer for extruding common brick. The product is entirely free from laminations.

The die is usually conical or sloping in cross section for the rear half or two-thirds of its length and almost uniform in cross section for the forward part.

The manufacture of floor tile offers special problems involving the same principles as are applied in the manufacture of stiff mud brick and roofing tiles.*

The brick made in auger machines may be either end cut or side cut, depending on whether the area of the cross section of the bar corresponds to the end or wide side (face) of the brick. The capacity of machines making end cut brick is generally increased by the use of double or triple dies. The general practice in Michigan is to use double dies, making end cut brick. This equipment can turn out easily from 35,000 to 75,000 brick a day under good conditions. The State plant at Onondaga has extruded 100,500 brick in nine hours using a four screw auger, making side cut brick. One pug mill extruding two streams is required to produce 300,000 to 325,000 end cut brick in eight hours in the Chicago district.

Extrusion machines using a piston or plunger instead of an auger are of two general types; the direct acting where a piston is forced against the clay by means of steam, compressed air, or water under pressure, and

[1]G. W. Shoemaker, Trans. Am. Cer. Soc. 14, p. 162 (1912).
W. H. Gorsline, Ibid 14, p. 546 (1912).

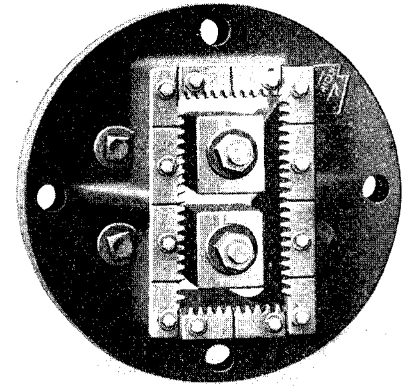

Plate XV, Figure 3.—Die for extruding hollow tile.

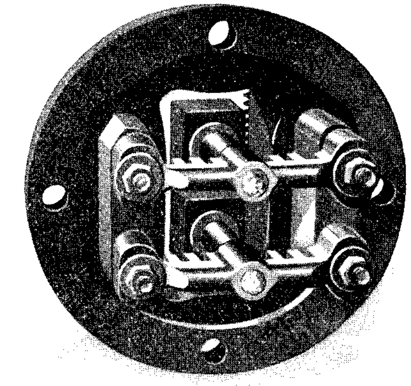

Plate XV, Figure 4.—Interior of die shown in figure 3.

(Cuts by Hadfield-Penfield Steel Co.)

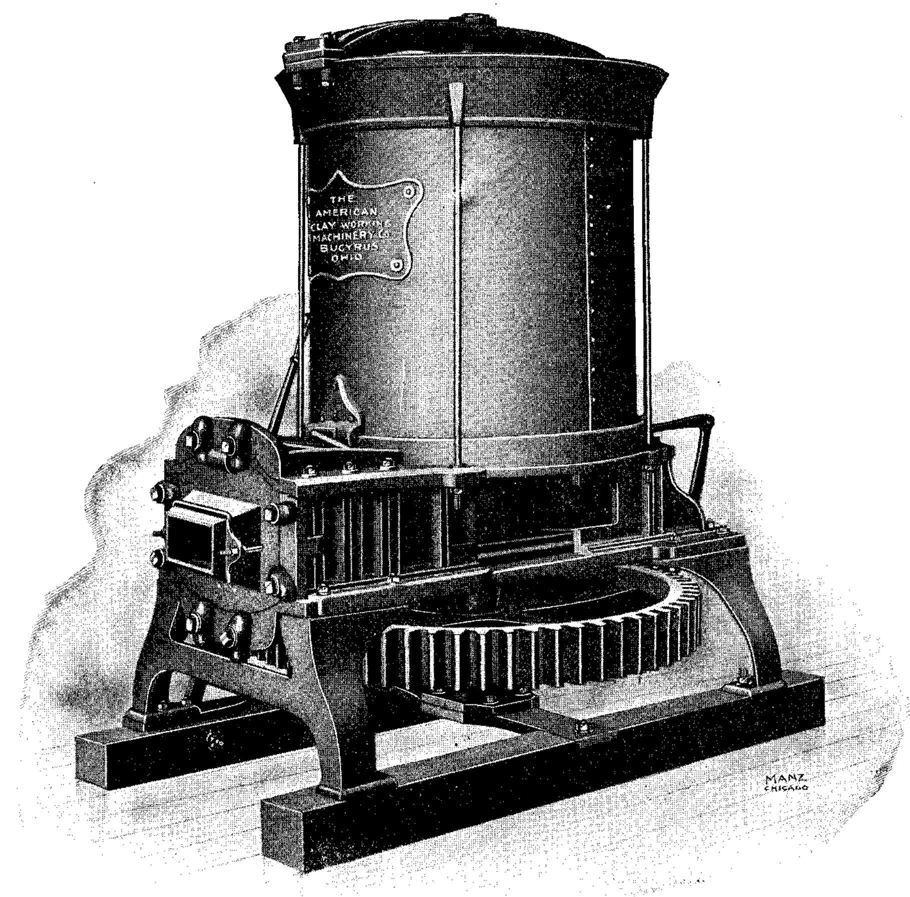

Plate XVI,—Piston extrusion machine. (Cut by Hadfield-Penfield Steel Co.)

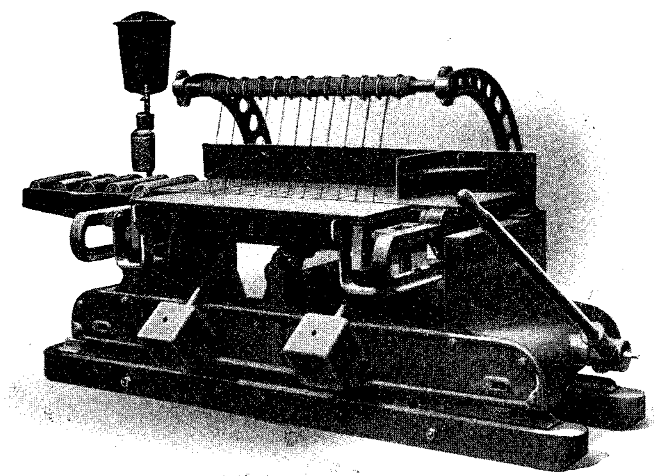

Plate XVII, Figure 1.—Board-delivery cutting table.

Ten brick are cut at each movement of the lever and the brick are deposited upon a pallet ready for the off-bearer. The wires are suspended on a movable cutting frame and the push board is stationary. By this means the slab of clay is cut into bricks without any waste. The operator stands at the end of the table farthest from the machine and operates the lever by which the wires are drawn across the slab, and the pallet, or board, is drawn under the brick while being cut. The cutting is done at the moment when the traveling column of clay abuts against a stopping plate near the operator, which starts the table to move with the column of clay. After the cut is made the operator pulls the table toward him, enabling the wires to clear the end of the traveling column of clay. The back stroke of the lever replaces the wires in their original position and deposits the pallet of brick at the front of the table so that it can be removed.

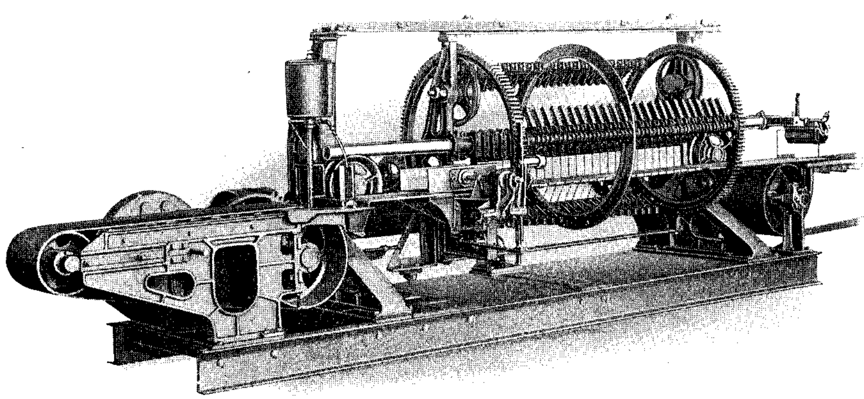

Plate XVII, Figure 2.—Automatic rotary cutting table. Capacity 6,000 to 15,000 brick per hour.

(Cuts by Hadfield-Penfield Steel Co.)

the indirect where the piston is forced by some form of mechanical gearing (Plate XVI). These devices have been developed in connection with the sewer pipe and brick industry respectively. The action of any such reciprocating machine is intermittent and offers serious disadvantages in irregular feeding and decreased output as compared to the continuous auger machine. However, some clays can be extruded by the piston machine that cannot be handled by the auger type, and in making large diameter shapes such as sewer tile, the auger machine is not practical, and the piston type is used. In extruding sewer pipe or large drain tile it is important that the issuing cylinder be compressed and not expanded as it passes through the die.*

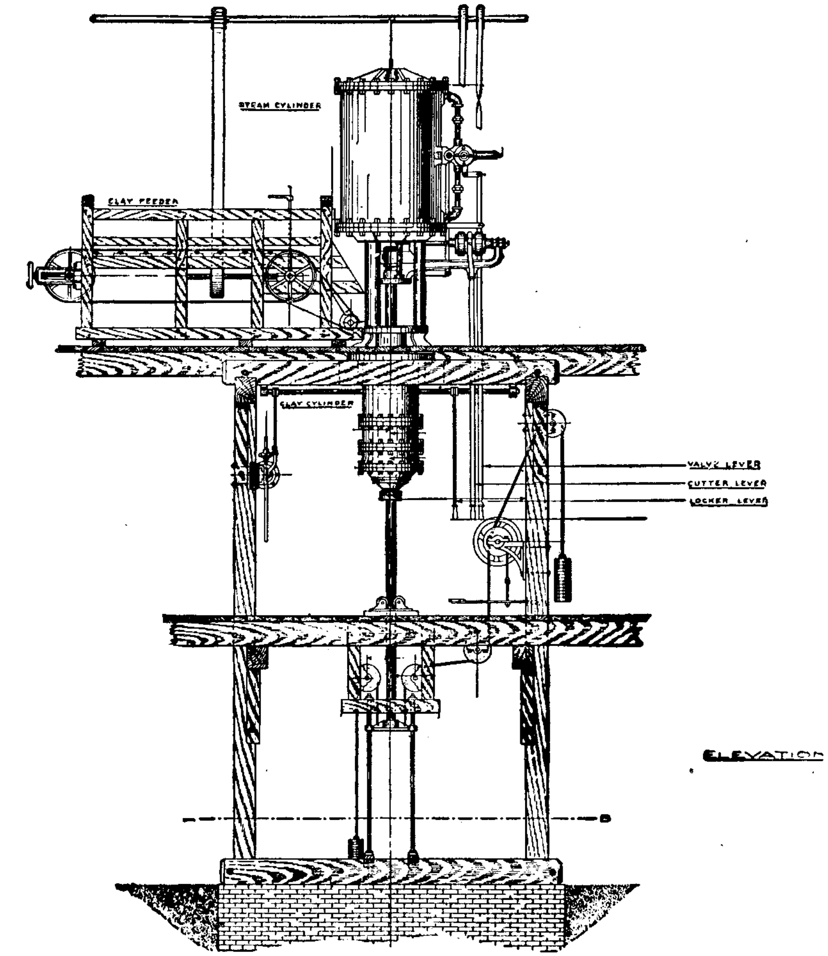

Figure 24.—Front elevation of sewer-pipe press.

Figure 24 gives in elevation the general layout of a sewer pipe press.

[1]G. D. Morris, Trans. Am. Cer. Soc. 19, p. 479 (1917).

The upper cylinder is the steam cylinder operating the piston which is continuous in the lower clay cylinder. The diameter of these cylinders is in a ratio which varies from 2:1 to 3:1. The piston being drawn up clear of the clay cylinder, tempered clay is fed into the clay cylinder by the belt conveyor. The piston descends under steam pressure forcing the clay out through the die at the lower end of the clay cylinder. The extruded pipe is supported on the counter-balanced pipe-table and cut off at the desired length. The cutting may be accomplished by hand, wire, or by a power driven cutter contained in the lower part of the clay cylinder. The diameter of the pipe so extruded varies from four inches to three feet, the length depending on the diameter and the capacity of the clay cylinder. The piston stroke is usually about 4 feet.

In extruding brick and tile, which is usually done by the continuous auger machine, the bar of clay issuing from the die is supported by a short length belt conveyor that carries the bar to the cutting table. The clay bar is cut into the proper lengths by fine wire tightly drawn across the projecting arms of the cutting machine. The cut brick are then picked up by a second belt conveyor traveling at a speed four to six times as fast as the clay bar. This distributes the green brick along the conveyor from which they are picked up and stacked on pallets or cars to be placed in the drier. In the smaller plants using open air driers, the pallet of brick is picked up on the two wheeled truck by running the prongs of the truck under the pallet, and conveyed to the drying yard where the pallet is set by a similar but reverse process.

The stiff mud process is adapted mainly to clays of moderate plasticity; very plastic clays are apt to show laminations to a high degree and give trouble in extruding; very lean or sandy clays do not give a well bonded dense product. When properly made, stiff mud brick or tile is a very dense strong product, free from laminations.

Repressing. When used for fronts of buildings where a fine appearing brick is demanded, stiff mud, or soft mud brick after a partial drying, are sometimes repressed to smooth the surface and straighten the edges. Fire brick made by either of these processes is always repressed. A brick may have a higher density and sometimes a greater strength after pressing, and is supposed to be free from any laminated structure. There is, however, a difference of opinion as to the effects of repressing, probably due to the different character of clay used. In many cases repressing has been found to be detrimental to the wearing qualities. No plant in Michigan now represses its brick.

Roofing tile is generally formed by repressing the blanks extruded by a stiff mud auger machine. Shingle, Mission, and Spanish tiles may be formed directly by the auger machine but all forms of interlocking tile must be formed by repressing.

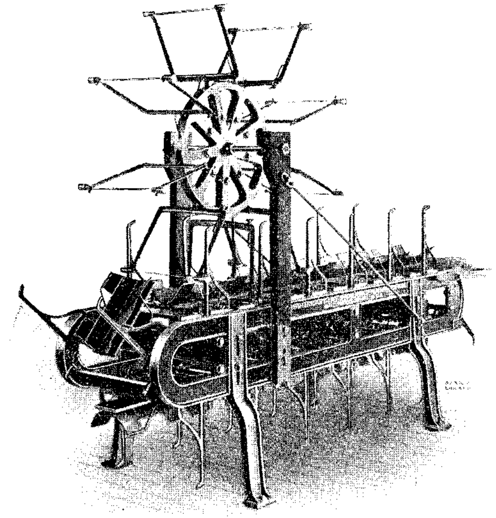

Plate XVIII, Figure 1.—Automatic cutter for cutting tile.

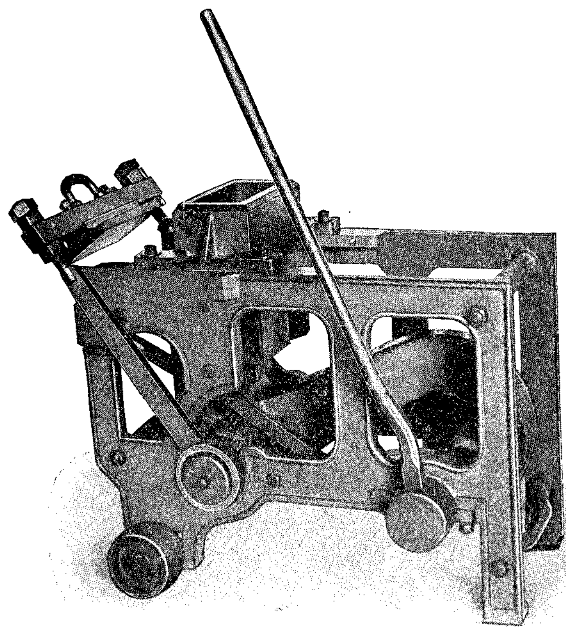

Plate XVIII, Figure 2.—Hand power brick repress.

(Cut by Hadfield-Penfield Steel Co.)

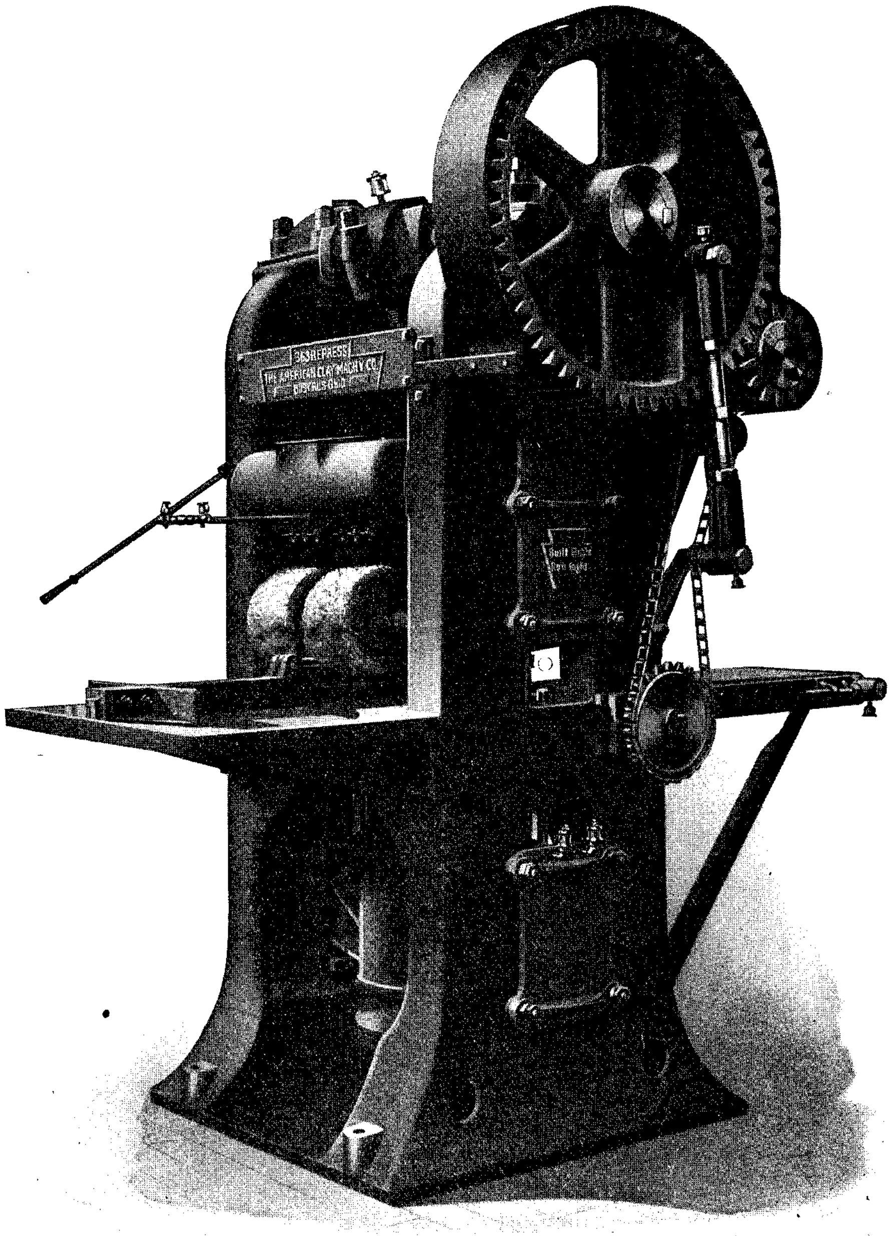

Plate XIX, Figure 1.—Front view, power driven repress. (Cut by Hadfield-Penfield Steel Co.)

Dry Press Molding. The so-called dry press method of molding brick uses clay that contains just enough moisture so that when pressed in the hand the clay will retain the form given it. The amount of water required varies from about 5 to 15 per cent. The clay is usually stored or aged for some time before use, and is then broken up by a disintegrator or dry pan and screened to about 12 or 16 mesh, then disintegrated and pressed directly. H. Spurrier[1] suggests drying to 16% moisture. The molding machine (Plate XIX) consists of a heavy steel frame carrying the delivery table about 3 feet above the ground with a press box sunk in the rear. The charger, connected to the clay hopper with a canvas tube, forms a framework which moves back and forth over the molds. It is filled on the back stroke and on the forward stroke lets the clay fall into the mold or press box. As the charger recedes a plunger descends pressing the clay into the mold, the bottom of the mold rises slightly compressing the clay. The pressure is relieved and applied a second time. The plunger then rises and the bottom of the molds lift the bricks to the level of the delivery table. The bricks are then pushed forward by the charger filled with clay as it advances to refill the molds. The bottom plungers in the molds descend allowing the molds to be filled. The faces of the mold and plunger are of hard steel and steam heated to prevent adherence of the clay. Sometimes greasing of the die is resorted to for the same purpose.[2] Air holes are also made in the dies to permit the air contained in the clay to escape. Otherwise this air would be compressed and when the pressure was released, its expansion would split the brick.

This method of forming produces in one operation a brick with sharp edges and smooth faces. Air drying may be eliminated as the bricks are dry enough to set immediately in the kilns, although there is still considerable moisture to be driven off during the early stages of burning and the bricks are more difficult to burn.[3] When hard-burned or vitrified, dry-pressed bricks are as strong as others, but they often show a granular structure.

The capacity of a dry press machine is about the same as that of a soft mud machine. The initial cost of the machine is fairly high, but this is probably more than offset by the saving in drying, so that this method is rapidly replacing repressed stiff mud brick. The stiff mud process has a greater capacity, and except for the drier, a lower initial cost, so that where repressing is omitted the dry press method offers little advantage.

This same method of dry pressing is applied to ornamental forms and has been tried unsuccessfully for manufacture of roofing tile.[4] Floor tile

[1] J. Am. Cor. Soc. V, page 151 (1922).
[2] Simco and A. F. Smith, Trans. Am. Cer. Soc. XIV, p. 558 (1913)
[3] Ellis Lovjoy, Trans. Am. Cer. Soc. 7, p. 232 (1905).
[4] Worcester, Ohio Geol. Survey series IV, Bull. 11, p. 288 (1910).

and wall tile may be made by the dry press process from carefully selected clay that has been prepared by washing, blunging, filter pressing, pugging, drying, and aging in the order mentioned. This is the same preparation given pottery clays with the addition of drying before aging.

Throwing. In forming pottery products the individual pieces must be molded separately. *Throwing* is done by the potter taking a lump of clay prepared and wedged, placing it in the center of a rapidly revolving horizontal disk, and gradually working it up into the desired form. After being turned the object is detached from the wheel by running a thin wire underneath it. Only articles with a circular cross section and thick walls can be formed in this manner, as they must hold their form without any support. Throwing represents the earliest method of the potter and is still employed except where jollying can be used to advantage.

Jollying. Jollying or jigging is more rapid than throwing. The jolly is a revolving horizontal disk or wheel fitted with a hollow head which holds the plaster mold whose interior corresponds to the outside of the object to be formed. A lump of clay tempered to a soft consistency is placed in the revolving mold and shaped to the proper form, first by the fingers and finally by means of a template or "shoe" attached to an arm which is brought down into the mold. Cups, jars, jugs, and the larger flower pots are formed in this manner.

A slight modification in using a revolving steel mold, with a steel plunger corresponding to the inside of the object, called jolly pressing, is used in making small flower pots. The tempered clay is put through a piston extrusion machine, the issuing bar being cut into pieces containing just enough clay for making one pot. These lumps of clay are placed singly in the mold which is raised by means of a lever until the plunger presses the clay into the mold. The bottom of the mold is movable and rises as the mold is lowered, pushing the pot free of the mold. These machines have a large capacity and are used at most flower pot factories. The same method is also used in molding small fire clay crucibles.

In making plates and saucers the clay is pounded into a flat cake, called a "bat," which is laid on a mold corresponding to the upper surface of the plate. The lower side is then formed by pressing a wooden template of the proper profile against the revolving clay.

Casting. Casting consists in pouring a clay slip into a plaster mold, which absorbs some of the water causing a thin layer of clay to adhere to the interior surface of the mold. When the layer of clay is sufficiently thick the mold is inverted, pouring out the remaining slip. After a few hours the mold is removed. In order to produce a slip of the proper consistency with less water, some alkaline salt is often added to the

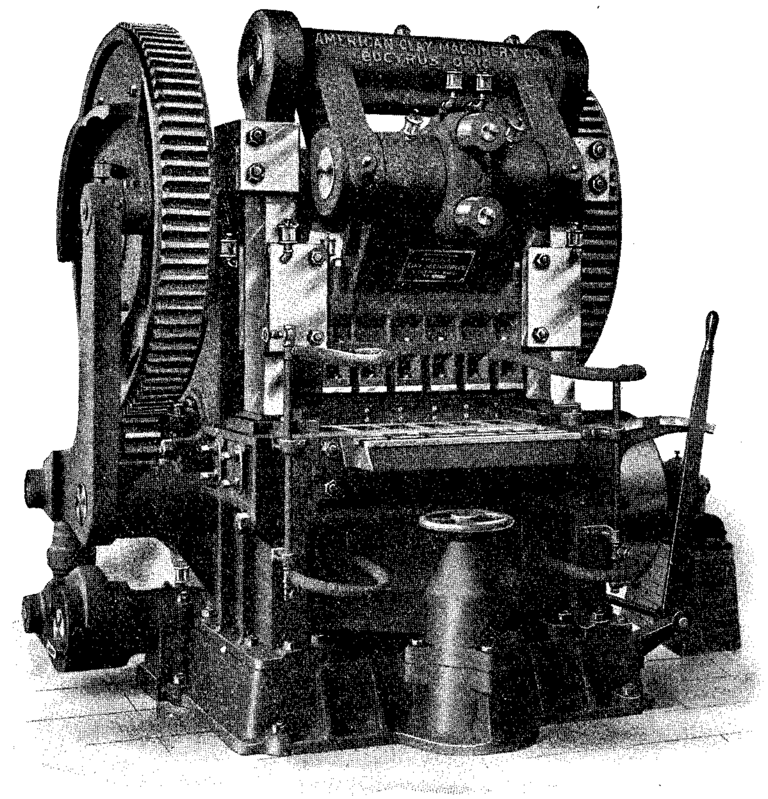

Plate XIX, Figure 2.—Power press for molding brick by the dry process. (From Hadfield-Penfield Steel Co.)

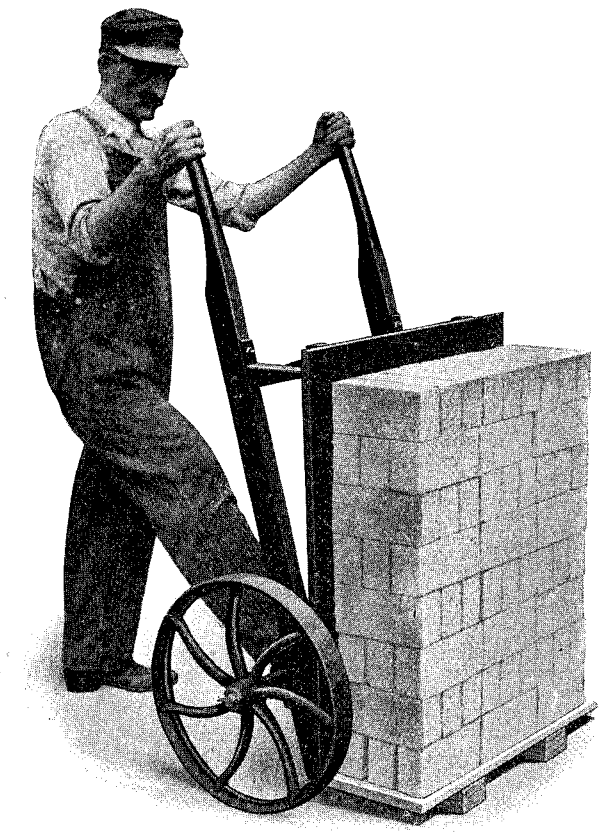

Plate XX.—Large pallet of stiff mud brick as trucked on two wheeled trucks in plants using open air drying. (Cuts by Hadfield-Penfield Steel Co.)

mixture. Casting is extensively used in making thin porcelain ornaments, white ware objects and belleek and may be used for heavy ware.[1] It has been tried in making terra cotta but so far has not proved satisfactory.[2]

Terra-cotta is the name applied to those clay products used for decorative structural work, which cannot be formed by machinery. Most plants use a mixture of several clays and a variable quantity of grog (ground fire brick, terra cotta, sewer pipe, etc.) to produce the proper plasticity with a limited shrinkage. The weathered clay is ground in a dry pan, tempered in a wet pan and pug mill. The tempered clay as it leaves the pug mill is cut up into lumps and aged until used, when it may be retempered and pugged.[3]

Hand Molding. Terra cotta is formed by hand, either in plaster molds ("pressing") or by modeling. The plaster mold is made in one piece for small simple designs, large objects and intricate shapes are formed in several pieces that are joined together when set in the building. In pressing a plaster mold the tempered clay is spread over the entire inner surface of the mold to a depth of about one inch and a half and pushed into all the corners and crevices, then the sides are connected by clay partitions to strengthen the piece. The mold is set aside for several hours to permit the clay to shrink enough to be removed from the mold.[4]

In making intricate undercut designs plaster molds cannot be used and the ware must be hand modeled by skilled workmen.

Drying.[5] The amount of water required to temper the different clays so as to develop their plasticity for molding, varies from about 15 per cent to 38 per cent of the dry clay. The problem of drying is to remove this water at the least expense under such conditions that the form of the ware is retained and its full strength developed.

The drying of clay ware depends upon vaporizing the water mixed in the clay and carrying this vapor away in a stream of air or other gas.

The molecules of a liquid such as water are in a state of constant unordered motion, some moving with great velocity and others with relative slowness. For any temperature, however, there is a certain

[1]Pottery Gaz. 45, p. 773 (1920).
[2]R. F. Geller, Trans. Am. Cer. Soc. IV, p. 883 (1921).
[3]R. L. Clare and R. N. Long, J. Am. Cer. Soc. IV, p. 453 (1921).
[4]John Clark, J. Am. Cer. Soc. 5, p. 623 (1922).
Klinefelter and Parsons, Ibid. 5, p. 632 (1922).
[5]Walker, Lewis & MacAdams, Principles of Chemical Engineering, pp. 436-551, McGraw Hill Book Company (1923).
E. Hausbrand, Drying by Means of Air and Steam.
Otto Marr, Drying and Drying Machinery.
T. C. Marlow, Drying Machinery and Practice.
E. A. Fisher, Proc. Royal Soc. (London) 103A, pp. 664-75 (1923).
R. F. Geller, J. Am. Cer. Soc. 4, p. 282 (1921).
M. G. Babcock, Trans. Am. Cer. Soc. 18, p. 564 (1916).
Ortman & Davis, J. Am. Cer. Soc. 4, p. 796 (1921).
D. T. Farnham, Trans. Am. Cer. Soc. 11, p. 392 (1910) described a double deck drier.
W. D. Richardson, Trans. Am. Cer. Soc. 6, p. 227 (1904).
R. H. Minton, Ibid 6, p. 269 (1904).

mean velocity of the molecules. But some molecules always possess a velocity sufficiently greater than this mean to overcome the attraction exerted between them and other molecules of water or clay and continue their motion out into the surrounding space, exerting a pressure upon the walls of the container as a resultant of the bombardment produced by their motion. As these molecules move in all directions a certain number will strike the liquid or moist solid from which they emanated and again become a part of it. When the number of molecules of water re-entering is just equal to the number leaving the clay, a condition of dynamic equilibrium exists. Under these conditions the water in the space surrounding the clay is said to be in the form of a vapor and the pressure exerted upon the container by this vapor is said to be the vapor pressure at the existing temperature.

If the space surrounding the clay be filled with molecules of some other substance, such as air, at about atmospheric pressure, the voids between the gas particles are sufficiently large and numerous to enable the above phenomenon to take place undisturbed. As the pressure on the container is due to the sum of molecular impacts, the total pressure on the walls is made up of the pressure of the gas originally present plus the vapor pressure of the liquid, or the partial pressure of the gas plus the partial pressure of the vapor.

If the clay is in contact with air in which the partial pressure of the vapor is less than the vapor pressure of the moisture in the clay, the moisture in the clay will vaporize. This vaporization of moisture absorbs heat which, if not supplied by some external source, must come from the moist clay. This fall in temperature of the clay is accompanied by a corresponding decrease in vapor pressure. Finally a temperature is reached where the vapor pressure of the liquid is equal to its partial pressure existing in the air and vaporization or drying will cease.

In order for vaporization to continue the following conditions must be met:

1. The heat necessary for vaporization must be supplied continuously.
2. The equilibrium which forms between the vapor pressure of the liquid and its partial pressure in the surrounding space must be continuously destroyed.

If the temperature of the air is higher than that of the moist clay, heat will be transferred from the air to the clay, raising the temperature of the clay. This will increase the rate of evaporation from the clay but decrease the rate of heat transfer from the air to the clay. This process will continue until a state of equilibrium is reached in which the heat supplied by the air exactly equals the heat absorbed by the water vaporizing.

When the drying process begins the water is uniformly distributed throughout the clay. As soon as the clay comes in contact with the drying air, evaporation will start at the surface, and the concentration of water on the surface will diminish. Because of this lower concentration of water on the surface, moisture will diffuse from the wet interior to the partially dried exterior, tending to keep the surface moist. In some cases the limiting factor is the rate of surface evaporation, while in others it is the rate of diffusion through the clay.

Very porous sandy clays with a very low drying shrinkage usually may be dried rapidly on the surface without cracking, but most clay products, particularly fine grained plastic clays, can be dried only so fast as the water diffuses from the interior. If the surface evaporation is rapid and exceeds the rate of diffusion from the interior, the surface becomes very dry, shrinks, and is placed under a high tension because of the relatively incompressible wet interior. This shrinkage, unless very small in amount, results in rupture or cracking of the surface. For this reason the rate of surface drying of clays usually must be carefully controlled so as not to exceed the rate of diffusion of moisture through the clay. As this rate of diffusion is increased by heating the clay, rapid drying can be accomplished without cracking only by using hot air of high humidity, high temperature for rapid diffusion and high humidity for slow surface evaporation.

Clay, or any solid, in contact with air has on its surface a relatively stationary film of air which seems to serve as an insulating layer between the air and the clay. This film is relatively thick when the motion of the air is slight. With higher velocities of the air this film decreases in thickness but never disappears. The rate of surface evaporation is dependent upon the rate of diffusion of water through this film of air. The inner layer of the air film in contact with the clay is practically in equilibrium with the moisture in the clay, or saturated if the vapor pressure of the moisture is sufficient. If the moisture in the outer air surrounding the body has a lower partial pressure, a partial pressure gradient of water vapor exists from the clay through the film to the outer air, and water vapor diffuses outward from the clay. Vapor reaching the outside of the air film is disseminated throughout the mass of the surrounding air so rapidly by convection, compared with the rate of diffusion through the stationary air film, that concentration differences of water vapor in the surrounding air may be neglected.

Open Air Drying. The oldest and simpest method used for drying brick consists in simply exposing the green brick to the natural air temperature and currents. In some cases where the climate permits the brick is laid on the ground or drying floor and exposed to the direct heat of the sun. The necessary heat is supplied by the sun, which makes this method inexpensive. Dry floors are brick floors heated by flues underneath the surface which carry hot gases from fires. The brick are placed on the hot floors which supply the heat instead of the sun. Uneven drying and high fuel consumption makes this type of drier very unsatisfactory.

In Michigan these procedures in outside drying have been entirely replaced by the use of pallets and drying racks of various forms. For drying soft mud brick the racks are made of a series of posts to which cross arms are fastened, so spaced that the pallets which receive the brick from the molding machine may be stacked on the cross arms in vertical rows of about eight to twelve pallets. Stiff mud brick are much stronger when green and are stacked on larger pallets, which are carried on the two wheeled trucks (Plate XX) to the drier and then righted on a low rack which supports this large pallet a few inches or a foot above the ground. The pallets are usually protected by a shed roof projecting over them on each side to protect the brick in case of storms. Frequently it is also necessary to protect the brick from the direct heat of the sun and strong winds during the first part of the drying period to prevent cracks. This is generally done by stretching canvas over the racks. The racks are of any length and must be spaced so as to be easily accessible by the wheelbarrows or trucks used to carry the brick.

This method increases the capacity of the yard and allows free circulation of air around the brick. Being protected from the direct rays of the sun, the brick dry slower and more evenly as the air has free circulation, with less tendency to crack and warp. Open air drying, however, allows practically no control of the three important factors in drying, *supply of heat, velocity of air,* and *humidity of air.* For this reason open air drying can be used only with clays that dry easily, where the time of drying can be varied to suit atmospheric conditions, and must be abandoned during the winter and other unfavorable seasons.

Drying in Sheds. In an effort to control the circulation of air and completely protect the ware from storms, drying is often conducted in sheds. These drying sheds are barn like structures, usually with a wooden slatted floor of narrow lumber with narrow spaces of about an inch between the boards, a foot or more above the ground, and drop doors on all sides. The green ware, such as drain tile, is stacked on end in the dry shed with all sides closed. The surface of the ware thus protected from draught has a rather thick adsorbed layer of air surrounding it, which acts much like a blanket or wet cloth allowing the surface to dry slowly. After drying has proceeded slowly for some time, usually one or two days, and the inside of the ware has shrunk with the surface, some of the drop sides are partially raised allowing more rapid air circulation. As the drying proceeds the sides are opened until the ware is ready for burning. In cold weather the sides may be kept closed and salamanders burned in the shed to supply the necessary heat and circulation. These drying sheds are used by many small drain tile plants in

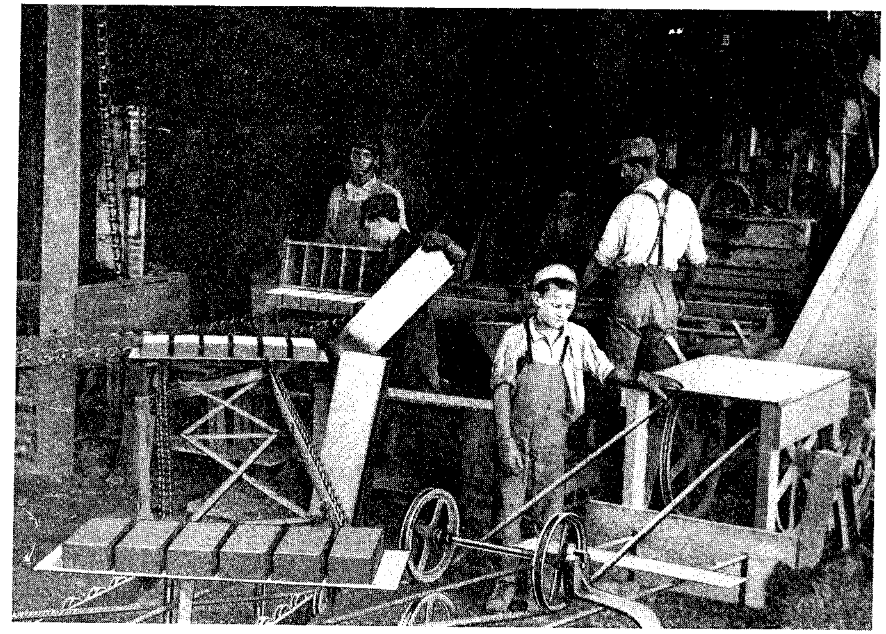

Plate XXI, Figure 1.—Soft mud brick carried from molding machine on pallet conveyor and empty pallets returned to molding machine as needed.

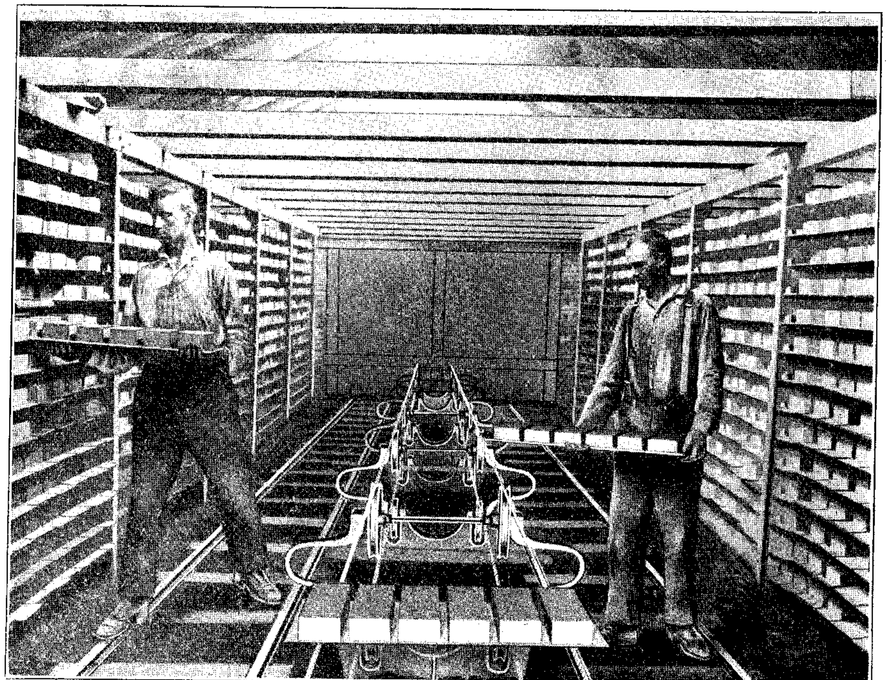

Plate XXI, Figure 2.—Unloading pallet conveyor in the chamber drier.

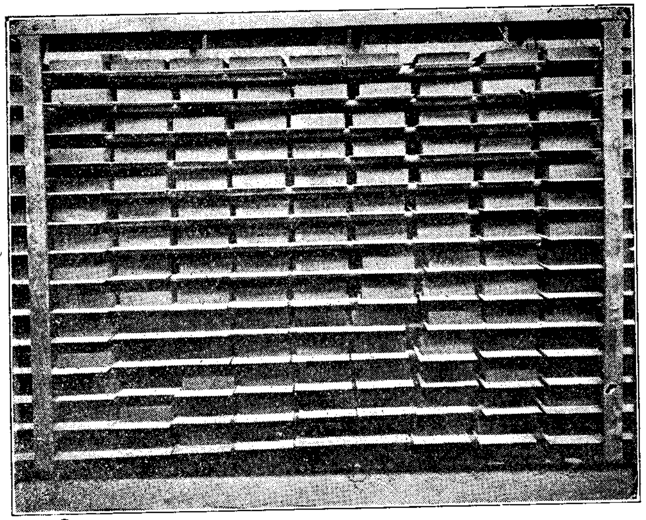

Plate XXII, Figure 1.—Drying racks made of steam pipe as used in the Detroit brick plants.
(From Lancaster Iron Works.)

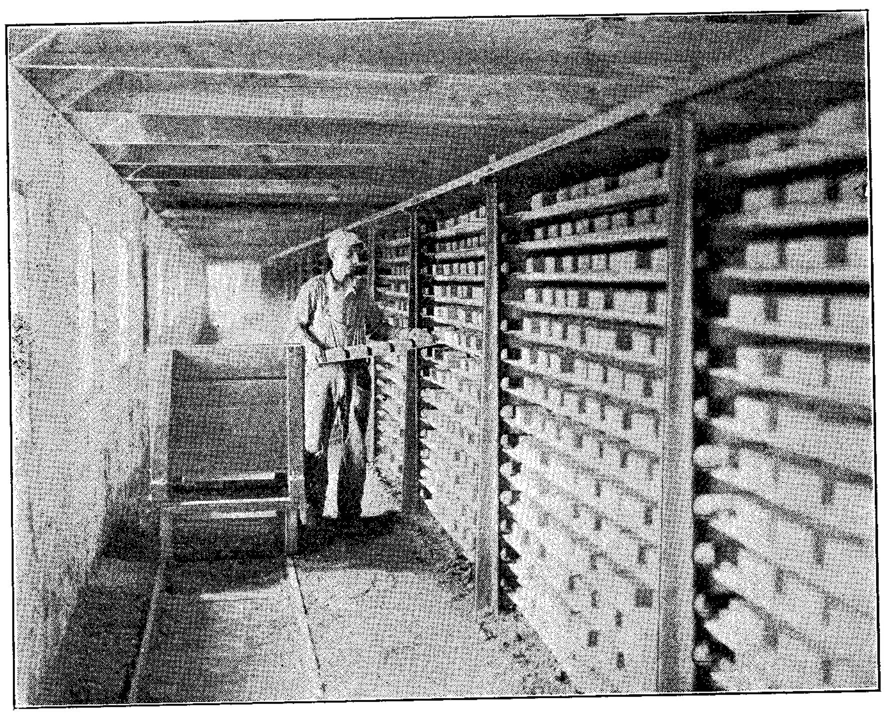

Plate XXII, Figure 2.—Unloading chamber drier.
(From Hadfield-Penfield Steel Co.)

Michigan with very satisfactory results. Sometimes these drying sheds are built around the burning kilns, in this way using the otherwise waste heat from the kilns to aid in drying the green ware.*

If the sheds are carefully built they may be called *room driers*. Roofing tile, terra cotta, and pottery are generally dried in room driers or dry rooms. Many of the large terra cotta pieces are dried at the point where they are made in the workroom, at least until drying has advanced beyond the shrinkage period and the pieces are strong enough to be safely handled, when they may be moved into smaller, hotter rooms and placed upon racks or slatted floors underlain by steam pipes. Sewer pipe is dried in the same building in which it is formed. The structure is usually three or four stories in height, containing slatted floors with steam pipes hung under the floors to supply the heat and circulation necessary. Elevators are used to aid in placing the green sewer tile.

Periodic or Chamber Drying. Periodic or chamber driers consist of one or more compartments with inlets and outlets for the air. The ware is placed in cars which are run into the tunnel on steel tracks or in the case of soft mud brick, placed on pallets (Plate XXI) which are carried or conveyed into the drier and set or stacked on racks. These racks are frequently formed by the steam heating pipes which run lengthwise of the tunnel and supply the necessary heat (Plate XXII). In these driers the temperature is approximately the same in all parts of a unit and is under the control of the operator, so that the brick may be heated gradually until completely dried. The air may be admitted through small flues in the floor connecting with a large air flue extending the full length of the chamber under the floor. The moist air may escape through chimneys placed along the chamber or tunnel, or through one large central stack. The air is frequently heated by steam coils before passing into the chamber, and in special cases the moisture content of the air is controlled and a large fan used to circulate the air. Sometimes the stack gas from the boiler, kiln, or other fire is blown through the chamber instead of air to supply all or part of the heat. When this is done, care must be taken that the sulphur dioxide does not condense on the moist brick forming calcium sulphate which persists as a white scum.

In operation the chamber is filled with green brick as molded. When filled, or at the end of the day's run, the chamber is closed and the steam turned on, usually in increasing amounts as the drying proceeds. In some car type driers the steam coil placed below the track is divided into three sections, which are turned on successively as drying progresses. With both the heat supply and air circulation under control, almost any clay can be dried successfully in a well designed chamber drier. The drier should be divided into one, or two-track tunnels or chambers, in

[1]This method is employed by the Miller City Company at their plant near Paines, Saginaw County.

order to obtain even circulation of the air. All steam pipes should be easily accessible for repair. Forced draft or fan circulation is always more reliable than natural draft which varies greatly with atmospheric conditions as the temperature of the air leaving the drier is not sufficiently above that of the outside air to insure a steady draft.

This type of drier is widely used in the Detroit district for drying soft mud brick. The day's production is run into the drier directly from the molding machine, on a conveyor which carries the pallets of brick down an aisle between two steam heated racks. The pallets are stacked on the racks until full when that chamber or tunnel is closed heated by exhaust steam, and the next one filled. When the day's production has been made, all of the steam is available for drying. The drying is completed over night, and on the following day the pallets are removed in the same order in which they were stacked in the drier. The dried brick are stacked on cars which are run into the kiln shed and the empty pallets returned by the conveyor to the molding machine as needed (Plates XXII, Figure 2 and XXI Figure 2).

The intermittent chamber driers are wasteful of heat, partly in that the air rises to the top of the drier and escapes before it has done all the drying possible, and especially because in removing the dry brick the entire chamber is cooled down before it is filled again.

Continuous Tunnel Drying. The continuous tunnel drier is widely used in modern brick plants. The tunnels are usually about 80 to 120 feet long, 5 feet high, and about 4 feet wide. Several tunnels constructed side by side, separated by walls, constitute the usual drier. If the tunnels are not separated the circulation of gases cannot be properly controlled. The roof should be flat to prevent spaces above the tops of the cars which allow the hot air to escape without coming into contact with the brick. Tracks are laid through the tunnels from the molding machine to the kilns. The tunnels are heated by steam, hot air, or hot gases, in much the same way as the intermittent tunnel kilns, except that the flow of gas or air is countercurrent to the movement of the brick.

Soft mud brick are dried on pallets stacked on racks on the steel cars. Stiff mud brick are stacked directly on each other on the cars, the rows being laid at right angles. The steel cars vary in capacity from 300 to 600 or 700 brick. When loaded the cars are pushed to the turn tables in front of the tunnel, turned to the proper track, and pushed in the cooler end of the tunnel where the gases escape through a stack. The next car pushed into that tunnel forces the others forward toward the hotter end of the drier where the gases enter. The capacity and length of the drier should be sufficient so that the cars may pass through the tunnels slowly enough to be gradually heated and dried without danger of cracking or warping. The hot gases enter the discharge end of the drier near the kilns through flues connecting to the lower end of the drier near the door. At this end the brick are almost completely dried and ready to be removed from the drier. The hot dry air or gas absorbs some moisture from these nearly dry brick and is cooled according to the amount of moisture vaporized. The air then comes into contact with the next car of brick which gives up some of its moisture to the air which steadily acquires a higher partial pressure of water vapor and a lower temperature. In this way the green brick come into contact with a relatively cool gas, with the high partial pressure of water vapor, which dries the brick very slowly with no danger of cracking. The partially dried brick in which shrinkage is about complete comes into contact with a hot dry gas which effectively removes the last of the moisture.

Many of the tunnels are heated by air and hot gases from furnaces built under the discharge ends of the tunnels. The hot gas carries the heat along the tunnel under the tracks through flues. Air admitted through openings on each side of the fire box is heated by the furnace and enters the tunnel. The moist air and waste gases escape through a stack at the charging end of the drier.

Sometimes the air is heated by a bank of steam coils at the discharge end. Some steam pipes may also be laid along the floor of each tunnel to aid in supplying the heat of vaporization. Such coils are usually equipped so that they may be heated by exhaust steam when the plant is running and by live steam otherwise.

Waste Heat Drying. In the larger plants it may be possible to obtain enough hot air from the cooling kilns to operate a drier.[1] The hot air from the cooling kiln is drawn from the top of the kiln by a fan and forced through the tunnels. This method uses heat that is otherwise wasted but is sometimes inadequate to supply all the heat necessary and steam coils or fires are relied upon to make up the difference. Bleininger[2] gives the following heat distribution in a plant using the principle of waste heat drying:

Sensible heat in kiln gases		27.33%
Burning bricks		19.55
Carbon in the ash		3.51
Waste heat to dryer	28.10%	49.61
Furnace and kiln radiation	21.51	
		100.00%

In a discussion of a paper by W. W. Ittner[3] a novel method of drying is described. One fan draws the hot gases from the downdraft kilns through a cast iron pipe in the floor of the drier. The heat convected from this pipe is sufficient to dry the brick.

[1]J. H. Kruson, Brick and Clay Record 59, p. 266.
[2]Trans. Am. Cer. Soc. 11, p. 153 (1909).
[3]J. Am. Cer. Soc. 5, p. 221 (1922).

The continuous counter current tunnel drier is easily adapted to different plants and to different clays. It is fundamentally efficient in the use of heat as the hot gas is completely cooled and saturated by its long travel through the cars of green brick. For these reasons the use of the continuous drier for drying brick and similar products is increasing. Sewer tile and similar ware take up such a large amount of space for a given weight of clay that continuous tunnel drying would not be as economical as the usual room drier.

Chapter VII

METHODS OF MANUFACTURE, CONTINUED

BURNING CLAY WARES[1]

The objects to be accomplished in burning clay wares have been briefly discussed and may be summarized in consecutive order as follows:

Watersmoking (drying)
Oxidation (and dehydration)
Shrinking (bonding)
Vitrification
Cooling (annealing)

Watersmoking. Generally the ware set in a kiln is far from dry, and some wares, such as dry pressed bricks, are placed directly in the kiln from the molding machine. Dry pressed ware usually requires about 5 to 8 days watersmoking and dried ware about 12 hours to 2 days, in the usual type of downdraft kiln. As scumming or kiln white may be caused by allowing sulphur dioxide in the fire gases to come in contact with the ware when it contains sufficient lime and moisture, watersmoking is sometimes done with wood when coal is used for the rest of the burning.

From the discussion of drying it is evident that heat must be supplied during watersmoking, and equally important that a large volume of air or gas be drawn through the kiln to remove the moisture. During the water smoking period, when a strong draft is needed, the temperature of the stack gases is low, creating only a weak natural draft.

R. F. Geller[2] claims that it is possible to watersmoke heavy clay products in 15 hours, raising the temperature 20°C per hour to about 300°C, by maintaining a good circulation of air as can be done by mechanical draft, and using thermocouples to control the rate of heating. W. W. Ittner[3] described results obtained by using fan to create neces-

[1]Ellis Lovejoy, Burning Clay Wares, T. Randall & Co., Indianapolis (1920).
Alfred B. Searle, Modern Brickmaking, Van Nostrand (1911).
Grum-Grzhimailo, Williams, Flow of Gases in Furnaces, John Wiley & Sons (1920).
Trinks, Industrial Furnaces, John Wiley & Sons (1923).
C. B. Harrop, Trans. Am. Cer. Soc. 18, p. 223 (1916).
E. H. Fritz, J. Am. Cer. Soc. 1, p. 294 (1918).
D. T. Farnham, Trans. Am. Cer. Soc. 13, p. 706 (1911).
T. W. Garve, J. Am. Cer. Soc. 5, p. 455 (1922).
H. P. Humphrey, Trans. Am. Cer. Soc. 9, p. 661 (1907).
J. B. Millar, Ibid, 9 p. 675 (1907).
W. J. Stephani, Ibid. 9, p. 681 (1907).
A. F. Hottinger, ibid. 9, p. 684 (1907).
A. Duckham, Engineering, 114 p. 534 (1922).
A. H. Davis, Phil. Mag. 40, p. 692 (1920).
C. R. Minton, J. Am. Cer. Soc. 7, p. 821 (1924).
Report of Committee of Refractories Manufacturers Assoc., J. Am. Cer. Soc. 5, p. 602 (1922).

[2]J. Am. Cer. Soc. 4, p. 375 (1921).

[3]J. Am. Cer. Soc. 5, p. 721 (1922).

sary draft for watersmoking in downdraft kilns, which lead to the conclusion that drying and watersmoking can be done much more rapidly and efficiently when forced draft is available.

Oxidation. Oxidation begins toward the end of the water smoking period and also requires a free circulation of gases. These gases must contain relatively large amounts of oxygen to effectively oxidize the carbon, sulphur* and iron in the clay. This same requirement must also be met to a lesser degree during shrinkage and vitrification. Most Michigan clays and shales begin to shrink at about cone 010 or 08, but do not develop a permanent bond giving a hard burned product below cone 02 or 1. Sample 5 of a surface clay gives a hard burned product at cone 08, and the sample 157 of carboniferous (Coal Measures) clay does not give a hard burned product until cone 3. Oxidation is not complete on disappearance of the black core but must be continued until the saffron colored core is thoroughly oxidized if best results are to be obtained.

Vitrification. Vitrification of the ware is obtained by increasing the temperature above that necessary for a hard burned product and holding it at a point necessary for fusion to proceed far enough to involve all of the mineral grains, giving a product of glass-like structure with very low porosity. There is no change in the burning process except that the clay is subjected to a soaking heat at a slightly higher temperature.

Common brick may be made by burning a clay to cone 1, but this temperature is maintained only for a short time, and the temperature in the kiln may vary seven or eight cones yet give a satisfactory yield of good brick. The same clay may be made into face brick and burned to a hard impervious product by firing to the same temperature, which is maintained for a much longer time until the difference in temperature throughout the kiln is reduced to three or at most four cones. This soaking heat at the same temperature allows the fusion to progress nearer to vitrification. In making vitrified ware the finishing temperature is nearer the failing point of the clay and greater care is required.

Cooling. Cooling is not, strictly speaking, a stage in burning, but many wares are greatly improved or toughened by proper annealing or slow cooling. It is well known that glass must be annealed to relieve the cooling strains and give it some degree of toughness, or the brittle mass would be of little practical value. Vitrified ware is much like glass and is frequently very brittle unless cooled carefully. The familiar snapping and cracking heard in a cooling kiln are evidences of the relief of the cooling strains developed in the cooling and contracting clay. Cooling cracks are very thin, hair-like, almost imperceptible closed cracks that may extend entirely through the ware. They may be readily shown by ringing two bricks together.

[1]Jackson, J. Am. Cer. Soc. 7, p. 656 (1924).

The cooling may take place rapidly down to a red heat, then the kilns should be closed, sealed with clay, and the dampers closed to prevent any cooling by convection of cool gases through the kiln.

Some clays are apparently not improved by slow cooling, or rather are not injured by rapid cooling. Every manufacturer should determine whether slow cooling is worth the additional time. It may be cheaper to stand the cooling losses than the cost of the slower operation.

KILNS

Clay has been burned in all parts of the world since the time when man was still savage. As this work has been conducted on a large scale as one of the prominent and essential industries for some centuries, it might be expected that the more crude, inefficient methods would have been eliminated. To some extent this has occurred, but an astonishing variety of old unscientific types of kilns are still used and even constructed.

Many new types are also being developed and it is not possible to state positively which kilns are more economical from all standpoints.

Classification. Kilns may be classified in a number of ways:

1. Method of firing
   - *Intermittent,* in which the green ware is set in the cold kiln, the fire started, the clay burned, the fires extinguished, and the ware and kiln cooled and unloaded.
   - *Continuous,* in which the green ware is pushed through the fire, or the fire moved around through the ware, in either case burning continuously, with all of the steps, watersmoking, oxidation, vitrification, and cooling always under way in some part of the kiln at the same time.
2. Direction of Flow of Gases while transferring their heat to the ware
   - *Updraft*
   - *Down draft*
   - *Horizontal draft*
3. Accessibility for machine setting
   - *Open top*
   - *Closed top or crowned*
4. Whether the furnace gases come into contact with the ware or not
   - *Direct Heat,* in which the fuel or gas comes into direct contact with the product.
   - *Muffle,* in which the ware is placed in a muffle or otherwise so protected that the furnace gases do not come into con-

tact with the ware which is heated by radiation or conduction from the muffle or by convection of the air within the muffle or chamber in which the ware is placed.

While other methods of classifying may be more satisfactory for certain purposes, in the present discussion these four general classifications help to identify the peculiar properties of the different kilns. Each of the classifications is all inclusive in itself, and each kiln should be properly placed in all four classifications, thus the first kiln to be described (the scove kiln) is an intermittent, up draft, open top, direct heat kiln.

INTERMITTENT OR PERIODIC KILNS

Up-Draft Kilns. The ancient clay workers burned their bricks in settings of rectangular form, the brick spaced so as to allow the hot gases from the fires to rise through the setting, and arched tunnels left in the bottom of the setting in which the fires were maintained.

Scove Kilns. The modern "scove" or "clamp" kiln widely used for burning common brick is essentially the same setting used by the ancients. The term scoved kiln applies to the mass of bricks themselves instead of the surrounding structure usually constructed after the bricks are set. The enclosing walls are usually built of broken or defective brick cemented over with mud to prevent excessive air leaks. These walls are 8 or 12 inches thick at the bottom, tapering off to 4 inches at the top.

On top of the kiln is laid a layer of green brick and over these at right angles to them a layer of burned brick, constituting the platting. Before the fires are started every alternate burned brick of the platting is placed on end to leave an opening for the escape of the smoke and vapors. Fires are built in each end of the "arches" which are exposed directly to the fire and are frequently overburned or even fused.

The cost of installation is very low compared with other kilns and the capacity is unlimited, usually ranging from 200,000 to 800,000. Because of the small cost of the kiln, amounting to no more than the cost of any storage space, the bricks are left in the kiln until sold, saving a double handling. Compared with other periodic kilns this type is economical of fuel. If the scove kiln gave a first class product it would be more widely used and very hard to displace. The product is not uniform either in color or degree of burning for a number of reasons.

As the kiln works on the up-draft principle temperature distribution is poor and difficult to control. If any part of the kiln becomes overheated, the gases in this part of the kiln are at a higher temperature than elsewhere, and therefore relatively less dense. These lighter gases are buoyed up to a greater extent than the cooler gases creating a greater

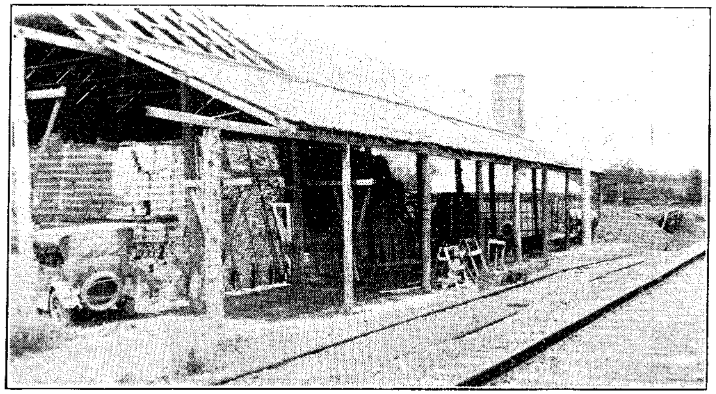

Plate XXIII, Figure 1.—Scove kiln shed, St. Clair Brick Co.

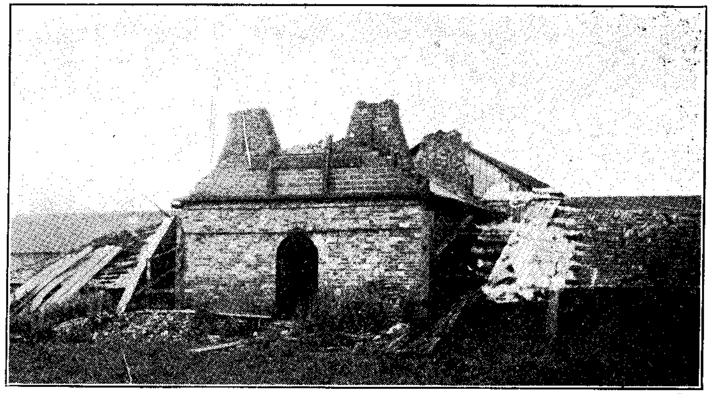

Plate XXIII, Figure 2.—Rectangular Stewart kiln used by East Cass, Macomb County.

Plate XXIII, Figure 3.—Circular down-draft kilns tile yards and operating force, Croswell Tile Co., Sanilac County.

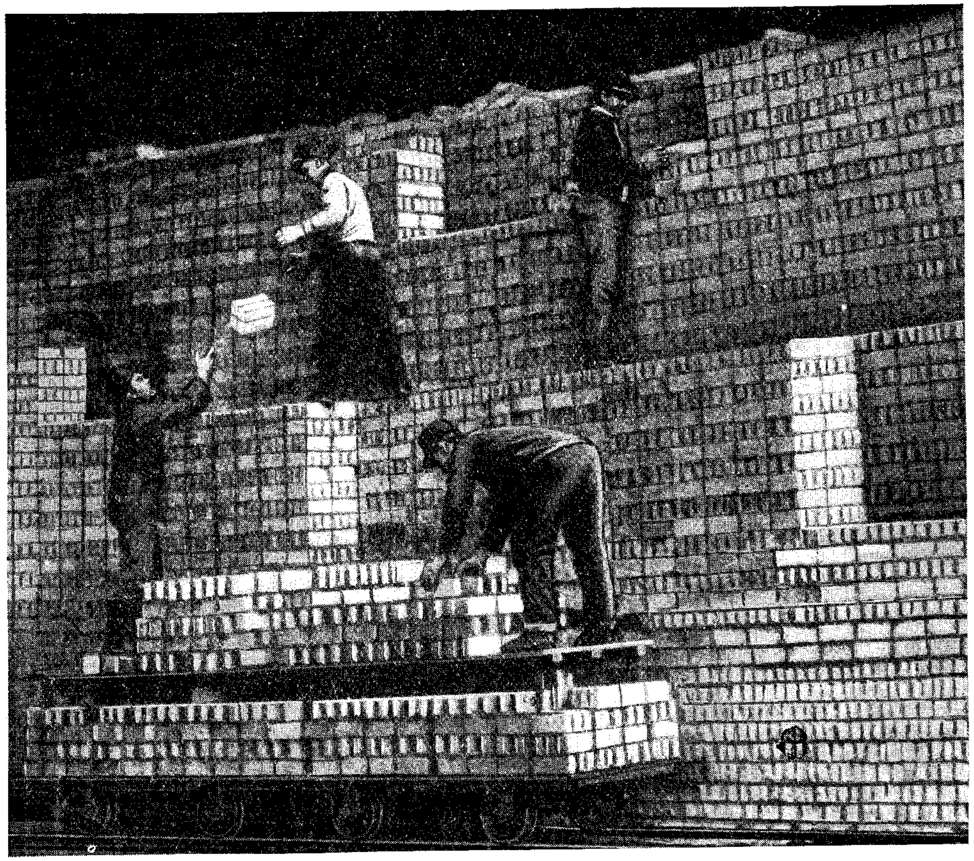

Plate XXIV.—Setting scove kiln.
(From Hadfield-Penfield Steel Co.)

draft through the hot part of the kiln. This increased draft causes an excess of hot gas to pass up through the hot part, making a bad matter worse. The hot part is called a chimney and may be controlled by tightly closing the platting or dumping dirt over that part of the kiln to destroy the draft and cause the hot gases to go elsewhere. Cold spots tend to become relatively colder for the same reason that hot spots tend to become hotter, and may be partially overcome by opening the platting over the cold spots and closing the platting over the hot chimneys.

The arch bricks are overburned, checked, spalled, warped, and blackened on the end exposed to the fire. The top bricks, often for several courses, and the sides and ends are almost invariably under burned, or soft. The yield of high grade, hard bricks of uniform color is small, in the face of a market continually calling for the better quality product. The heat distribution in a vertical direction may be somewhat improved by closing the platting and covering the top with dirt during the later stages of the burning. This holds the gases back at the top, making the burning somewhat slower and preventing the formation of chimneys, resulting in a harder burned product at the top. However, the additional cost is seldom thought to be warranted and the practice is not common.

All Michigan plants using the scove kiln burn their brick in kiln sheds (Plate XXIII). The usual arrangement is a large shed with a board roof completely covering the kiln and sometimes a lower shed roof or sides to cover the fire pits. The main shed roof frequently has a monitor in the center to carry off the gases and vapors from the tops of the kiln. Even then if the roof is at all low the boards are removed during the period of high firing. The kiln shed is usually laid out lengthwise across the discharge end of the drier with a railroad siding or wagon road on the other long side of the shed.

The green bricks are set in benches, the legs of which are from 2½ bricks (21 inches) to 4 bricks (34 inches) wide, with a space of 12 to 18 inches between the legs for the fire arch. The height of the setting is usually about 40 to 54 courses of brick on edge. The former height being determined by the ability of a man, (the tosser) to toss the bricks in units of 4 or 5 to the setter (Plate XXIV). Higher setting requires an intermediate tosser. The setting begins at one end of the shed and as soon as 4 or 5 arches or benches have been set, the end and sides are closed, cased, and sealed, and the fires started. The sides of the kiln are cased as the setting progresses. The setting of succeeding kilns is continued in this manner to the far end of the shed. Meanwhile the kilns are burned, cooled, and loaded, and the setting starts again at the first end. If market conditions are good the kiln shed will be kept clear for setting. If the bricks are not moved the setting overtakes the loading and the season is usually closed.

Lambert Firing Method. F. H. Lambert* has developed a novel method of firing scove kilns which is used at many of the plants in the Chicago district. The kilns are fired by oil atomized by steam and directed against a "target brick" which rapidly becomes heated and aids in burning the oil. In this way enough air is inducted with the oil independent of any draft through the kiln. The firing is carried on rapidly for about 18 hours or until the kiln has started to settle, indicating that the lower courses are completely burned. The oil is then shut off and steam used to induct air through pipes inserted in the arch after the oil is turned off. The steam and air forced through the kiln in this manner carries the heat up through the kiln, completing the burning as shown by the temperature time curves of figure 25 recorded at every seventh course.

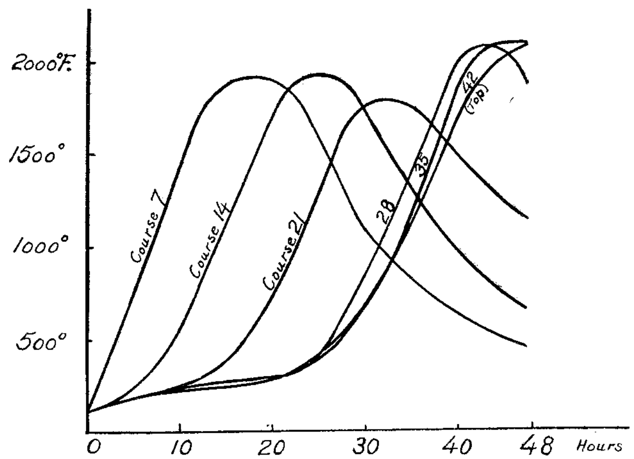

Figure 25.—Lambert firing curves.

Up-draft Kilns. The "up-draft kiln" is an open top, intermittent kiln essentially in every detail a scove kiln inclosed in heavy permanent walls (Plate XXV). The cost is higher and the burning conditions no better than in the scove kiln, but the permanent walls offer the following economies in operation.

1. Save labor in scoving and sealing the kiln.
2. The platting bricks are piled on top of the walls and do not have to be tossed up and down.
3. Permanent furnaces of better type and construction.
4. Less radiation loss and slightly better heat distribution.
5. Adequate support to the setting eliminating the spreading and failure of the setting as occasionally happens in a scoved kiln.

[1]Clayworker 75, p. 244-8 (1921).
Brick and Clay Record 66, p. 112 (Jan. 20, 1925).

The necessity of removing the brick through the doorways in the ends of the kilns is sometimes a disadvantage but usually negligible.

A crowned (closed top) periodic up-draft kiln, is seldom used in the ceramic industries except in burning pottery.* Its use here is largely due to tradition, as much better heat distribution can be obtained in a down draft kiln without much, if any, greater fuel consumption. In all up-draft kilns the hottest part is at the bottom. In burning products that are stacked one on another this is an important consideration, because the bottom layers must support the entire weight of the upper courses and if these lower courses are overburned they soften and are readily deformed under the load they are carrying. Occasionally when it is desired to burn different products at the same time in a kiln the uneven heat distribution in an updraft kiln may be utilized, if understood by the potter, to a slight advantage.

Down-draft Kilns. In down-draft kilns the hot gases first strike the ware in the upper courses, and the highest temperature exists in the upper part of the setting. If the brick in the upper layers should be overburned they would have no tendency to become deformed as they are not subject to any pressure. As the burning and vitrification are promoted by pressure the lower courses will be hard burned at a somewhat lower temperature than the upper courses. For these reasons, and particularly because of the better heat distribution, the down-draft kiln is widely used for many products,—common brick, face brick, fire brick, paving block, drain tile, conduit, sewer pipe, building block, stone ware, and special ware. Although the continuous kilns are steadily replacing the periodic down-draft kilns the latter are at present the most widely used type. In any kiln built on the down draft principle the hot gases enter over the ware and pass down through the setting. If any part of the setting is hotter than the rest, the gases in the hot part, being less dense than in the rest of the setting, will be buoyed up and less of the hot gases from above will flow down through the hot part. The hot gases tend to flow down through the cold parts of the setting, thus automatically making for even heat distribution.

Because of the fundamental feature all down draft kilns must be closed on the top. But all the advantages of loading an open top kiln can be obtained by making the top arches of a down draft kiln in steel supported sections that may be lifted off. There are very few kilns of this type of construction in use in the ceramic industries and none in Michigan. The removable arches are expensive to build and must be handled carefully to avoid rapid depreciation, but are easily repaired without shutting down the kiln. As the arches are frequently the most

[1]See F. H. Riddle, Trans. Am. Cer. Soc. 13, p. 385 (1911), for drawings of 12 Ft. up draft potters' kiln.