DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
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THEIR MANUFACTURE, PROPERTIES USES, AND SPECIFICATIONS

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ABSTRACT

This paper contains a brief history of the manufacture of fire-clay brick and of the growth of technical research and of the industry in this country, together with essential information regarding the manufacture of fire-clay brick and the classification, properties, and uses of the finished product. Since the quality of fire-clay brick and the uses to which they are adapted depend largely on the raw clays used, the paper also contains a brief discussion of the geology of these materials, their classification, and the characteristic properties of each class. In addition, the history of the development of the United States Government Master Specification for Fire-Clay Brick, together with this specification and a list of the principal references to literature on the subject of fire-clay brick, is given.

CONTENTS

I. INTRODUCTION

Fire-clay brick forms the oldest and most important division of that group of products technically referred to as "refractories" and broadly defined as embracing all materials used in the arts for the construction of heat-resistant containers.

1. EARLY HISTORY

While the primitive ruins of Europe indicate that copper was first smelted in shallow pits in the ground rather than in kilns, the history of fire-clay brick no doubt had its beginning some time during the bronze age. This is indicated by Egyptian hieroglyphics and reliefs which show the melting of copper and bronze in crucibles as early as the time of Senefern (about 3700 B. C.). Not only were the crucibles made of clay, but this method of processing required the use of some type of furnace or kiln. It was in the construction of these kilns that fire-clay brick were probably first used, and this method of manufacture was later adopted in the manufacture of brass and iron. A typical brass melting furnace of the eighteenth century is shown in Figure 1.

This illustration of a typical manufacturing method of its time serves also to emphasize the rapid development of the art of metallurgy during the following two centuries, by far the greater part of this development being concentrated in the last 60 years (in 1865 the United States produced less than 1,000,000 tons of pig iron, while in 1924 the production was estimated at approximately 35,000,000). The use and importance of clay refractories have increased in even greater proportions, since they are necessary not only to the metallurgical industry but also in the manufacture of such essentials to our modern civilization as Portland cement, sanitary ware, glass, and vitreous enamels.[1]

2. HISTORY IN UNITED STATES

In the United States the fire-clay beds of New Jersey are probably the first to have been discovered, and it is said that the first fire brick were made in 1812. In 1825 a plant was being operated at Woodbridge, N. J., in 1833 another plant was erected by John Watson on the Raritan River, and the present plants of Henry Maurer & Sons and of M. D. Valentine & Bro. were established in 1861 and 1865, respectively. It is believed that clay stove linings, made in Connecticut as early as 1836, were manufactured from New Jersey clay.

[1] A Practical Treatise on the Manufacture of Bricks, Tile, Terra Cotta, etc., by Charles Thomas Davis, contains considerable general information of historical interest. (1889) Henry Carey Baird & Co., 810 Walnut Street, Philadelphia.

The manufacture of fire-clay brick in Pennsylvania probably began shortly after the discovery of beds of fire clay and coal in Clinton County about 1830. The first permanent development in this county was started in 1836 by the Queens Run Fire Brick Co. Other developments followed with the discovery of the Bolivar, Clarion County, and lower Kittanning clays. About this time (1837) manufacturing operations were also begun at Mount Savage, Md., by the Union Mining Co.

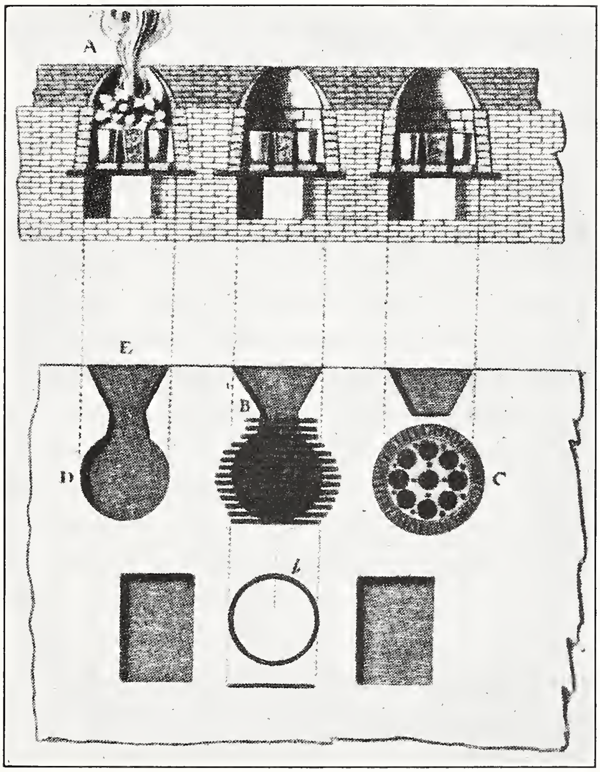

Fig. 1.—*Brass melting furnace of the eighteenth century*

Illustration from paper by Galon before the Academie Royale des Sciences, 1764

The fire-brick industry followed the advance of the frontier to the westward. Fire clay was discovered along the Ohio River in 1840, a small plant started two years later at Wellsville, Ohio, and in 1846 another small plant began operations at Hammondsville, Ohio. In the same year (1846) the manufacture of fire-clay brick was started in St. Louis, Mo., and from this time on the industry developed rapidly in both States. During the period from 1850 to 1880 new deposits of clay were found, and plants built, in the Canal Dover, Strasburg, Portsmouth, and Oak Hill districts of Ohio and in central Missouri.

In Kentucky the Lewis County clays were first mined about 1870 for the manufacture of brick in Cincinnati. Ten years later the famous Kentucky clays of the Olive Hill district were discovered, and the growth of the industry in that locality has been rapid, there being at least five plants in operation other than the original one at Ashland.[2]

Fire clays have been found, as smaller deposits, in several other States, among which might be mentioned Illinois, Colorado, California, Washington, and recently considerable research has been carried out on the clays of Georgia to determine their value as raw material for refractories.

3. GROWTH OF INDUSTRY

The industry, in general, has shown a most satisfactory growth, as indicated by the census of business transacted. In 1895 the production of fire brick was valued at $5,279,004. In 1905 this value had more than doubled, in 1910 the valuation was placed at $18,111,474, and the latest available estimate places the value of the production of fire-clay refractories for the year 1923 at $46,449,570. In 1924 this had decreased approximately 5 per cent. At the same time the value of fire-clay exports has increased from $144,552 for 1916 to $303,675 for 1923. The importation of German glass-pot clay appears to be slowly recovering from the setback due to the war and has nearly reached the value for 1914 ($122,325), the value for 1923 being placed at $121,272.

4. GROWTH OF RESEARCH

The year 1895 marked the formal beginning of ceramic education in this country and the consequent establishment of a nucleus for the permanent growth of technical knowledge and research.[3] Probably the first American literature of note on the clay industries appeared in various geological reports, the more important being those of Doctor Cook on the clays of New Jersey (1878), of Dr. H. Ries,[4] and of Edward Orton, jr., on the clay industries of Ohio.[5]

However, many of the State reports were fragmentary and, except in certain cases, such as noted above, there was no correlation of data, and the conclusions drawn were often based on insufficient data or could not be applied in practice. Consequently, the Federal Government was requested to establish under its jurisdiction a bureau for the centralization and furtherance of knowledge of the clay-working industries.[6]

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[2] C. B. Stowe, Brick and Clay Record, **58**, No. 11; May 31, 1921.
[3] Jour. of Am. Ceramic Soc., Bulletin, p. 89; March, 1925.
[4] N. Y. Geological Report No. 10, 1891, and many others.
[5] Geological Survey of Ohio, 7; 1893.
[6] A. V. Bleininger, Jour. of Am. Ceramic Soc., p. 145; January, 1923.

There resulted the establishment of a ceramic laboratory in the United States Geological Survey (1908), which was transferred to the Bureau of Standards (1910), where researches on ceramic subjects were continued without interruption under the direction of A. V. Bleininger.

The need for research in ceramic problems was given a decided impetus by the late war and has brought about greatly increased activity both in universities and in the Federal bureaus. Added to this, a cursory study of the literature will show a rapid growth in the number of papers from laboratories of industrial organizations and plants. A conservative estimate of annual appropriations in the United States alone for ceramic teaching and research, other than that from private sources devoted to individual problems and for personal gain, is approximately $400,000. This sum is ample evidence of the remarkable spread of interest in the scientific and technical phases of the industry. The nature of the researches relating to refractories carried out by the Bureau of Standards since 1910 can be determined by a study of papers listed in the appendix.

II. SCOPE OF WORK

Sections IV, V, and VI of this paper are devoted to a brief and nontechnical description of the classes and properties of the principal raw materials used in the manufacture of fire-clay brick, the methods of manufacture, and the general properties and uses of the finished product.

The laboratory investigations on which the specifications given in Section VI were based are reported in detail in Bureau of Standards Technologic Paper No. 279. The investigation was confined to a study of brick used in the settings of coal-fired boilers and to that class known to the trade as "first-quality brick." The specifications themselves were evolved with the cooperation and advice of representatives from Government departments and from manufacturers and users in the industry.

III. ACKNOWLEDGMENTS

The manuscript of this paper was prepared by R. F. Geller, with the assistance of Dr. H. Insley, who wrote the section on the geology and classification of raw materials; and, A. F. Greaves-Walker, professor of ceramic engineering at the North Carolina State College, and George Balz, president and general manager of the Seaboard Refractories Co., who offered many helpful criticisms and suggestions.

IV. RAW MATERIALS

1. GEOLOGY AND CLASSIFICATION

The argillaceous deposits of the earth's crust can be divided into three types—slate, shale, and clay—all of which were originally derived from igneous rocks; that is, rocks which solidified from the molten state. The action of weathering agencies on these rocks disintegrated the minerals containing alumino silicates (chiefly feldspars), removed the alkalies and some of the silica, and converted the remaining alumina and silica into hydrous aluminum silicate minerals. Kaolinite and other minerals of this type are the principal constituents of clays.

Although clays are composed essentially of hydrous aluminum silicate minerals, they vary greatly in purity and may contain many minerals carrying silica, alumina, iron oxides, alkalies, lime, and other constituents.

Shales and slates are like clays in chemical composition but differ markedly from them in appearance and structure. Shales are formed from clays and have become laminated by the pressure of overlying beds of rocks. Slates are formed from clays and shales which have become hardened by high pressure and temperatures due to earth movements.

Since clays are complex in origin and in properties, they are usually difficult to classify. A classification by Orton[7] based on quality and use is given below. It is not very satisfactory, because clays of different quality are often used for the same purpose and clays of the same physical character are often used for different purposes.

Orton's classification

High-grade clays (50 per cent or more kaolin with silica)	1. Kaolin. 2. China clay. 3. Porcelain clay. 4. Fire clay (hard). 5. Fire clay (plastic). 6. Potter's clay.
Low-grade clays (10 to 70 per cent kaolin with notable per cent fluxing elements)	1. Argillaceous shale. 2. Ferruginous shale. 3. Silicious clays (dense burning). 4. Tile clays. 5. Brick clays. 6. Calcareous shales.

Ries's[8] classification is somewhat more satisfactory, because the major divisions are based on origin and the minor ones on qualities.

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[7] Orton, Ohio Geological Survey, **7**, p. 52.

[8] Ries, "Clays—Occurrence, properties and uses," p. 27; 1906.

Ries's classification

A. Residual clays (by decomposition of rocks in situ).
  1. Kaolins or china clays (white burning).
    (*a*) Veins, derived from pegmatites.
    (*b*) Blanket deposits, derived from extensive areas of igneous or metamorphic rocks.
    (*c*) Pockets in sandstone, as indianite.
  2. Red-burning residuals, derived from different kinds of rocks.

B. Colloidal clays, representing deposits formed by wash from the foregoing and of either refractory or nonrefractory character.

C. Transported clays.
  1. Deposited in water.
    (*a*) Marine clays or shales. White-burning clays; ball clays. Fire clays of shales; buff-burning impure clays or shales.
    (*b*) Lacustrine clays (deposited in lakes or swamps). Fire clays or shales. Impure clays or shales, red burning. Calcareous clays.
    (*c*) Flood-plain clays, usually impure and sandy.
    (*d*) Estuarine clays (deposited in estuaries), mostly impure and finely laminated.
  2. Glacial clays (found in glacial drift), may be either red or cream burning.
  3. Wind-formed deposits (some loess).
  4. Chemical deposits (some flint clays).

Bleininger [9] divides the principal refractory clays into three classes—kaolin, flint clay, and plastic clay.

Kaolins are usually residual in origin, and consequently the crystals of which they are composed are fairly coarse and their plasticity low. When washed, they are usually white in color. The higher-grade kaolins sometimes approach very closely the chemical composition of the mineral kaolinite, $Al_2O_3.2SiO_2.2H_2O$, and their softening point is approximately equal to that of pyrometric cone No. 35.

Flint clays are so called because when dry they are dense and hard, have a waxy luster, and break with a conchoidal (flinty) fracture. In other respects they resemble kaolins, having low plasticity and a high softening point (cone 31 to 34). The higher-grade flint clays approach in composition the formula $Al_2O_3.2SiO_2.2H_2O$, and in many deposits the alumina content exceeds this ratio.

The plastic refractory clays are generally sedimentary or alluvial in origin. The dense-burning types contain higher percentages of silica and impurities than do the flint clays and consequently have a lower softening point (cone 27 to 31). Because of their plasticity these clays are widely used as a bond in refractory materials.

Another type of clay which has become important in the refractories industry in the last few years is the aluminous clay. Clays of this type, as a rule, contain alumina in excess of the ratio $Al_2O_3.2SiO_2$, the typical minerals being either gibbsite ($Al_2O_3.3H_2O$)

[9] Bleininger, A. V., in Liddell's Handbook of Chemical Engineering, pp. 491–493; 1922.

or diaspore ($Al_2O_3.H_2O$). The well-known high-alumina clays of Missouri contain diaspore, and this mineral is also found in segregated deposits. Where the diaspore content is high, the clays often have an oolitic appearance. Diaspore clays are in demand because of their high softening temperature and their resistance to slagging action. Their plasticity is, however, very low and they must usually[10] be mixed with a more siliceous, plastic clay in order that they may be worked in the unburned state. Diaspore clays have an unusually high shrinkage during burning, which apparently can be eliminated only at high temperatures and by repeated burning. It is frequently necessary to preburn them and use them as grog[11] in order that the refractory shapes may not crack or show mechanical weakness in service.

A detailed description of the origin and modes of occurrence of clays can not be taken up here, and therefore the idealized diagram shown in Figure 2 was drawn to illustrate the different ways in which clays may be formed. It is improbable that the topographic and geologic features in any particular area on the earth's surface are related in the manner shown, but it is thought that all structural relationships shown are geologically possible. The geologic history of the region shown in the diagram (fig. 2), deduced from the structural relations, would be about as follows:

The oldest rocks preserved in the region are a complex mass of metamorphosed, igneous, and sedimentary rocks (*R*). Perhaps originally granites, shales, sandstones, and limestones, they have been changed by the heat and pressure of earth movements and overlying rocks to confused masses of slates, quartzites, and marbles. Erosion leveled the land and earth movements tilted it toward the east and caused the submergence of the eastern portion in the sea. Marine sediments, consisting of beds of limestones and shales (*L* and *S*), were laid down comparatively near the shore. After this period of quiet deposition mountain making began with the upturning and folding of the sedimentary beds. The movements were accompanied by intrusions of molten igneous rock (*M*), and an inlet from the sea, formed by the upbuilding of these mountains, received sediments from the seaward and landward sides. These were principally shales and clays. The increasing thickness of the sediments, combined with a slight rise of the seacoast, then caused the expulsion of the sea from the inlet, and this was replaced by a sluggish, meandering river. East of the mountain range rapidly flowing streams (*V*) carried to

[10] Brick have been made successfully of diaspore without additional bond and by both the "dry-press" and "handmade" methods (for descriptions of method of forming see V). The diaspore is given a soaking or "weathering" treatment for a week or 10 days before being used to develop the plasticity as much as possible. To eliminate shrinkage, the brick are of the "grog" type (see VI), and both the grog and the brick must be burned to cone 18 to 20 (1,425 to 1,475° C.).

[11] See VI, 1 (*b*).

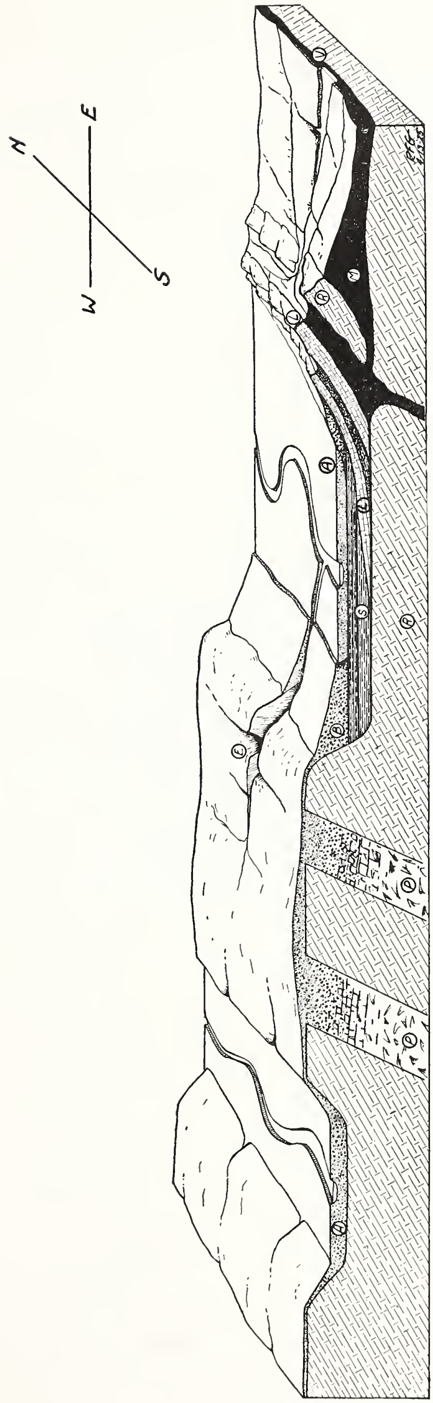


Fig. 2.—*Ideal photography showing formation of various types of clays*

A. Flood plain clays—reworked outwash aprons.
B. Outwash clays formed by deposition of clays removed by mountain streams.
E. Residual clays derived from weathered pegmatite.
L. Argillaceous limestone.
M. Igneous rock.
P. Pegmatite.
R. Basement complex of metamorphosed igneous and sedimentary rock.
S. Clays and shales deposited by marine waters.

the sea sediments resulting from the disintegration of limestones and igneous rocks.

During the time of (or shortly after) the intrusion of the molten rock to the east dikes of fluid and gaseous material at high temperature were forced into the basement rocks of the central highland. On solidification these became pegmatites (*P*) composed largely of quartz and feldspar. Weathering of the pegmatites formed mantles of rather pure kaolin (*E*) of the residual type over this portion of the country, and streams carried the material away to form fans of alluvial clays (*B*) at the foot of the plateau.

In the meantime the argillaceous limestones (*L*) in the mountains to the east were acted upon by the rains and groundwaters and slowly dissolved, the residual argillaceous soils forming clay banks at or near the foot of the mountains. The main rivers flanking the central plateau reworked the outwash material from the pegmatites and redeposited it as flood-plain clays in the valleys.

The diagram represents, therefore, the formation of clays of the following types:

1. Residual clays from pegmatites.
2. Residual clays from argillaceous limestone.
3. Alluvial clays in outwash aprons.
4. Alluvial clays in flood-plain valleys.
5. Marine clays.

TABLE 1

Eras	Periods	Important clay deposits
Cenozoic	Quarternary	Brick and tile clays from glacial, alluvial, and loess deposits in many States.
	Tertiary	Plastic kaolins in Florida; sedimentary kaolins and bauxites in Georgia; ball clays in Kentucky and Tennessee.
Mesozoic	Cretaceous	Sedimentary kaolins in Georgia and South Carolina; sagger clays in Tennessee; fire clays in Alabama, Colorado, Iowa, Mississippi, and New Jersey; bentonite in Wyoming and other States.
	Jurassic Triassic	No important high-grade clay deposits.
Paleozoic	Carboniferous:	
	Permian	Do.
	Pennsylvanian	Refractory clays and fire clays in Illinois, Indiana, Iowa, Kentucky, Maryland, Missouri, Ohio, Pennsylvania, and West Virginia; flint clays in Kentucky, Missouri, and Pennsylvania; indianite in Indiana.
	Mississipian Devonian Silurian Ordovician	No important high-grade clay deposits.
	Cambrian	Residual kaolins from shales and schists in Virginia and Pennsylvania.
Pre-Paleozoic	Pre-Cambrian	Residual kaolins from pegmatites of pre-Cambrian in North Carolina.

In lieu of a detailed discussion of the clay formations of the United States in the geologic time table, the chart (Table 1) has been arranged to show the chronological succession of the principal geologic subdivisions and to indicate the age of the better-known clay formations.

2. METHODS OF MINING

There are two distinct ways of obtaining the fire clays used in the manufacture of fire-clay brick—open pit and drift mining. In the latter three general methods are followed, namely, entering the vein directly from an outcropping, sinking a shaft to the vein, and by stoping.

(*a*) Open Pit.—In open-pit mining (fig. 3) the soil and subsoil (*S*), commonly referred to as "overburden," are first removed by means of steam shovels or scrapers (depending on the nature and thickness of the deposit). The desirable clay (*C*) is then usually loosened by blasting with black powder and removed with steam

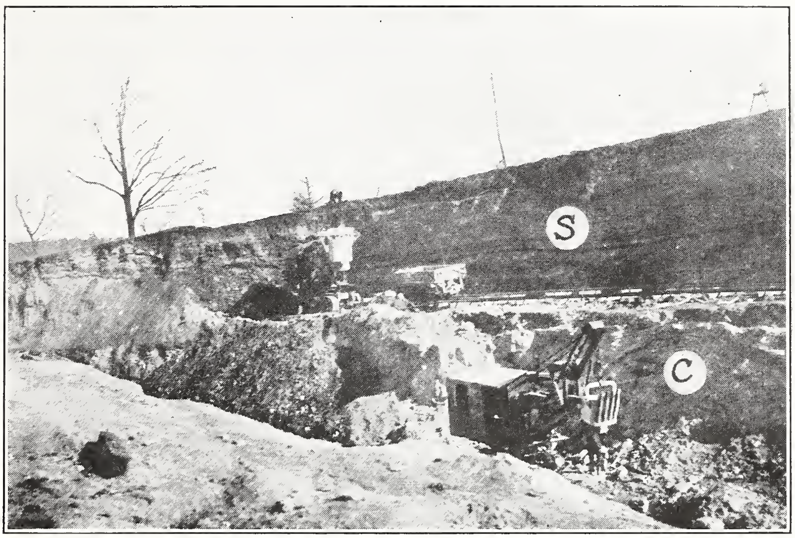


Fig. 3.—*Open-pit mining*

shovel and dump cars. For graded clays it may be necessary to hand pick the material to insure freedom from possible inclusions of sandstone or other injurious impurities (fig. 4). The loaded dump cars are then drawn by cable or other means directly to the plant storage piles or to cars if the clay is to be transported. Naturally, more primitive methods involving hand labor and horse-drawn wagons are to be found in small pits and in outlying districts.

(*b*) Direct Entry.—Directly entering an outcropping is often possible in districts of irregular topography (fig. 5). One or more entries are driven in from the face or exposed surface of the vein, and from these entries cross tunnels, or break throughs, are dug at intervals of 50 to 100 feet. From the break throughs tunnels are dug at right angles until the entire system, if exposed, would present a checkerboard appearance of tunnels and blocks (or pillars) of clay.

FIG. 4.—*Hand-picking of clays in an open-pit mine*

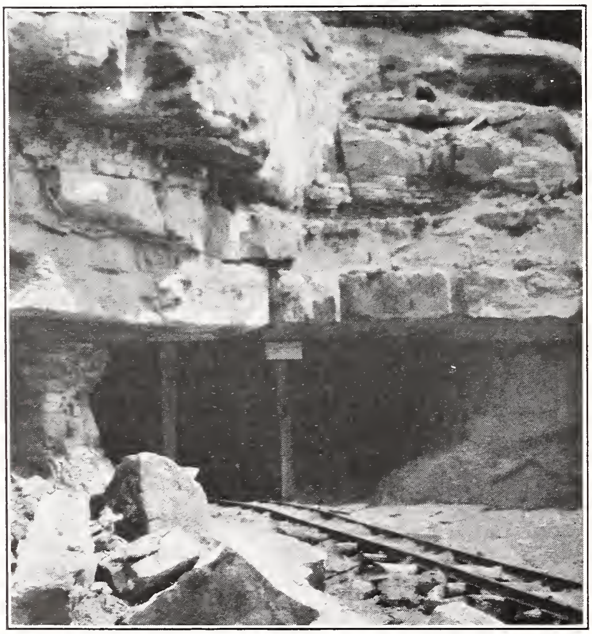


FIG. 5.—*Direct entry into a vein of clay*

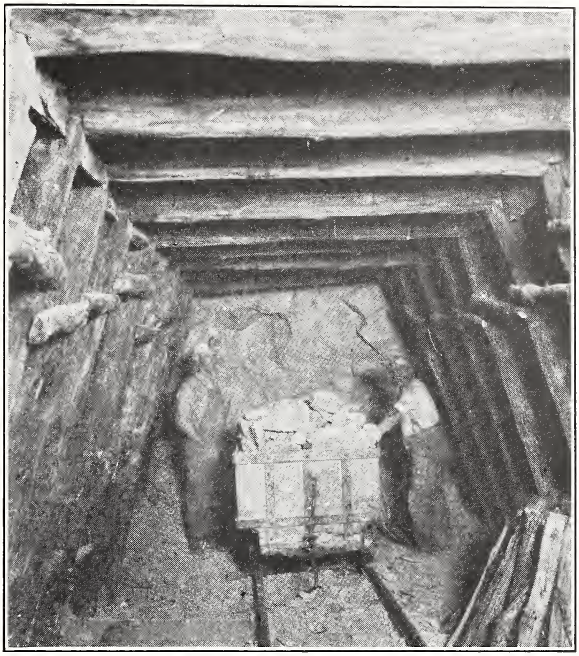


FIG. 6.—*Tunnel in underground mine showing heavy timbering*

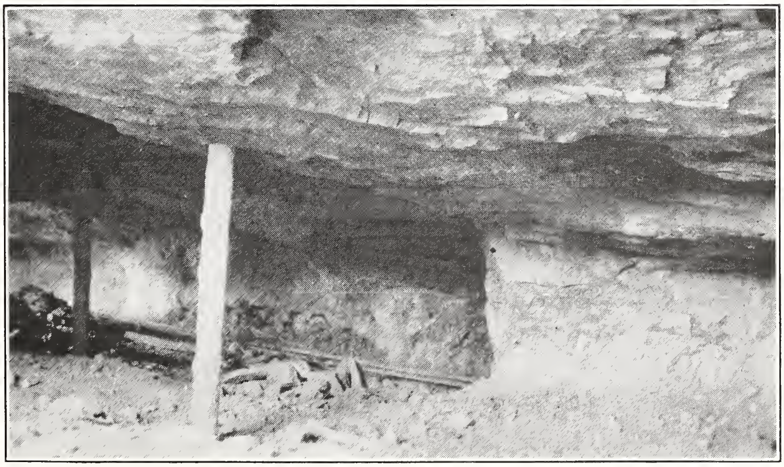


FIG. 7.—*Tunnel in underground mine having a sandstone roof and requiring practically no timbering*

When the vein has been mined thus as far back as practicable, the pillars of clay are mined, beginning with those farthest from the entries, since the mine roof will collapse after 60 to 80 per cent has been removed.

The amount of timbering or propping which is necessary to prevent the caving in of these tunnels depends on the nature of the roof. If it is shale, it will be fairly strong at first, but weathering soon weakens the structure, so that the distance between props must be decreased from an average of 8 feet to not over 24 inches (fig. 6). If the roof is more durable in nature, for example sandstone, propping can be practically eliminated (fig. 7).

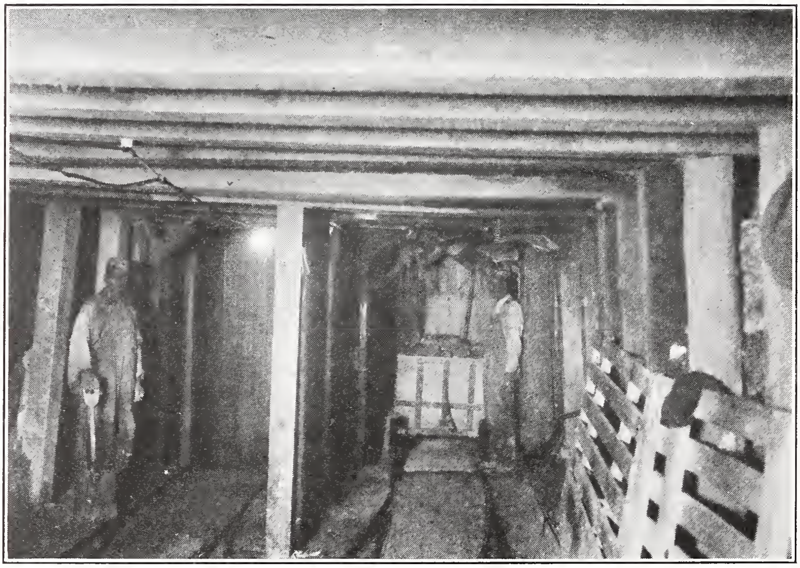


Fig. 8.—*Showing foot of shaft in an underground mine*

As in open-pit mining, the clay is blasted with black powder, loaded in small cars of about 1-ton capacity, called pit boxes, and hauled to the storage piles or to box cars.

(*c*) Shaft Entry.—When the clay vein is not exposed and is practically horizontal, a vertical shaft is sunk to it and, from the bottom of the shaft, entries and cross tunnels are driven along the vein. The general procedure from this stage on is essentially the same as mining from direct entry. There is this exception, of course, that the clay, after being hauled to the shaft, must be elevated to the surface (fig. 8).

(*d*) Stoping.—This method of mining is peculiar to the Colorado district and is made possible by the tilted position of the veins of clay (fig. 9). Entry is effected either directly into the exposed vein on the hillside (at *E*, fig. 9) or by means of a horizontal tunnel into the face of the hill and at a convenient point on the slope (fig. 11 at *E*). At the point where the entry meets the vein a cross tunnel is driven horizontally, and from this cross tunnel risers are dug at right angles, and upward, following the vein to the outcropping (at *O*, fig. 11). The clay is then mined by blasting it loose and permitting it to roll to the bottom of the riser, where it is fed into pit boxes, as desired, by means of chutes.

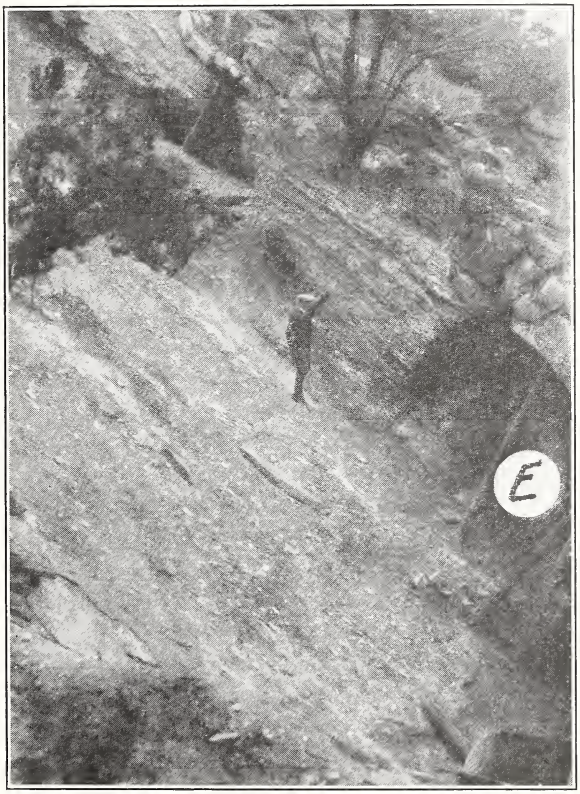


FIG. 9.—*Direct entry into an inclined vein of clay where the stoping method of mining is used*

In Figure 10 is shown the appearance of such a mine at the outcropping and after the vein has been removed with the exception of pillars which are left to support the roof.

With every method of mining, local problems of transportation, drainage, lighting, or ventilation arise which must be met in the way best suited to the circumstances. Descriptions of details might be of value in a few instances but useless in most cases and are therefore omitted.

3. COST OF MINING

The average cost of mining by the open-pit method is only a little lower than that from underground. As the depth of cover stripped increases, the cost naturally rises and no stripping is done where the overburden is so great as to make the cost greater than that of clay from underground.

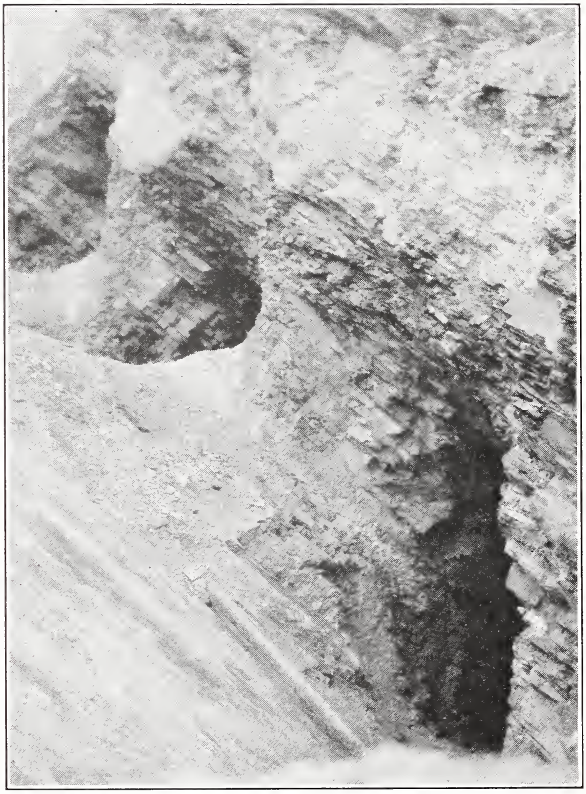


Fig. 10.—*Outcropping of an inclined vein of clay where the stoping method of mining was used and where all the clay has been removed with the exception of the pillars left to support the roof*

The cost of the clay from underground mines delivered to the railroad cars naturally varies a great deal with the following factors:

Labor rate, which is lower in the South than in the North and East.

Thickness of clay bed.

Presence of faults and amount of their displacement.

Mine drainage conditions.

Character of the roof and necessity for timbering.

Tendency of the clay to air-slake along the walls of the mine working.

The character of the clay, whether hard or soft (flint or plastic).

Method of mining, whether by shaft, slope, or adit.

Distance from mine mouth to railroad.

Method of transportation from mine to railroad.

Local labor and housing conditions.

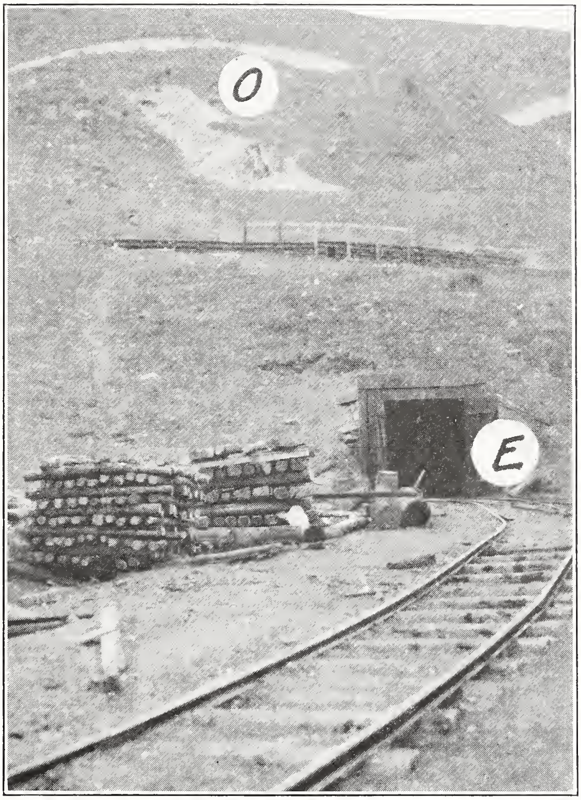


FIG. 11.—*Horizontal shaft entry into an inclined vein of clay*

Depending upon these factors, the cost of various clays from underground mines will vary from $1.50 to $4 per ton delivered to the railroad cars. With the possible exception of some New Jersey open-burning clays, it costs more to mine flint clay than plastic clay for several reasons. The flint-clay beds are usually not so thick as those of plastic clay, the clay is harder, the output per miner per day is less, and the distances from the mine to the railroad is usually greater; the flint-clay mines are also more pockety and faults are more frequent.

V. MANUFACTURE

1. FORMING

Handmade, soft mud, stiff mud, and dry press are the four generally recognized methods of forming fire-clay brick.[12] Of the various types of clays described under the section on "raw materials," the flint fire clays and plastic fire clays are most used. A mixture or "blend" of two or more of these clays is generally used, the relative percentages depending on the service for which the product is intended. In addition to the clays mentioned, some products also contain certain percentages of grog (preburned clay), silica (added as sand, gannister, or quartzite), and the aluminous materials, bauxite and diaspore.

It can be said, in general, not only of the "handmade" process but of the other processes, that the ways and means adopted for transporting the clays, the partly completed, and the completed products, will vary from all hand labor to various labor-saving devices, or combinations of these, depending on the funds available for equipment or the ingenuity of the men in charge. This should be borne in mind in reading the following descriptions of plant processes in which the more recent methods will usually be considered.[13]

(*a*) HANDMADE PROCESS.—Practically all special shapes, large blocks, and some brick of the 9-inch series [14] are being made by the handmade process. Flow sheet No. 1 is typical.

From the storage piles the clay and other ingredients are usually [15] fed directly to the dry pans by means of gravity or of belt conveyers, and from the dry pans the material is screened and delivered to bins for temporary storage

A dry pan (fig. 12) consists of (1) a steel pan about 1 foot deep and usually from 7 to 9 feet in diameter, carried on a vertical shaft; (2) two grinding wheels or mullers revolving about independent horizontal shafts supported on heavy springs. The mullers are heavy iron wheels from 10 to 12 inches thick and from 40 to 50 inches in diameter, equipped with replaceable manganese steel rims.

Motion is imparted to the mullers by the revolving pan, which, in turn, is driven either from above or below by means of a bevel gear on the vertical shaft and pinion on the drive shaft. The mate-

[12] In the specifications (VII) brick are defined as covering all burned units of standard or special shapes. However, units other than those comprising the "9-inch series" as defined by the Refractories Manufacturers Association are commonly referred to as "shapes." See Appendix for illustration of brick of the 9-inch series.

[13] Details of manufacturing methods can be found in past and current issues of practically all periodicals devoted to ceramics. Special reference is made to A. F. Greaves-Walker's "The manufacture of refractories in America," Trans. of the Brit. Ceramic Soc., **22**, Pt. IV, and to "The manufacture and properties of refractories for air furnaces," C. E. Bales, Trans. Am. Foundrymen's Assoc.; 1922.

[14] See appendix.

[15] Some material requires preliminary crushing.

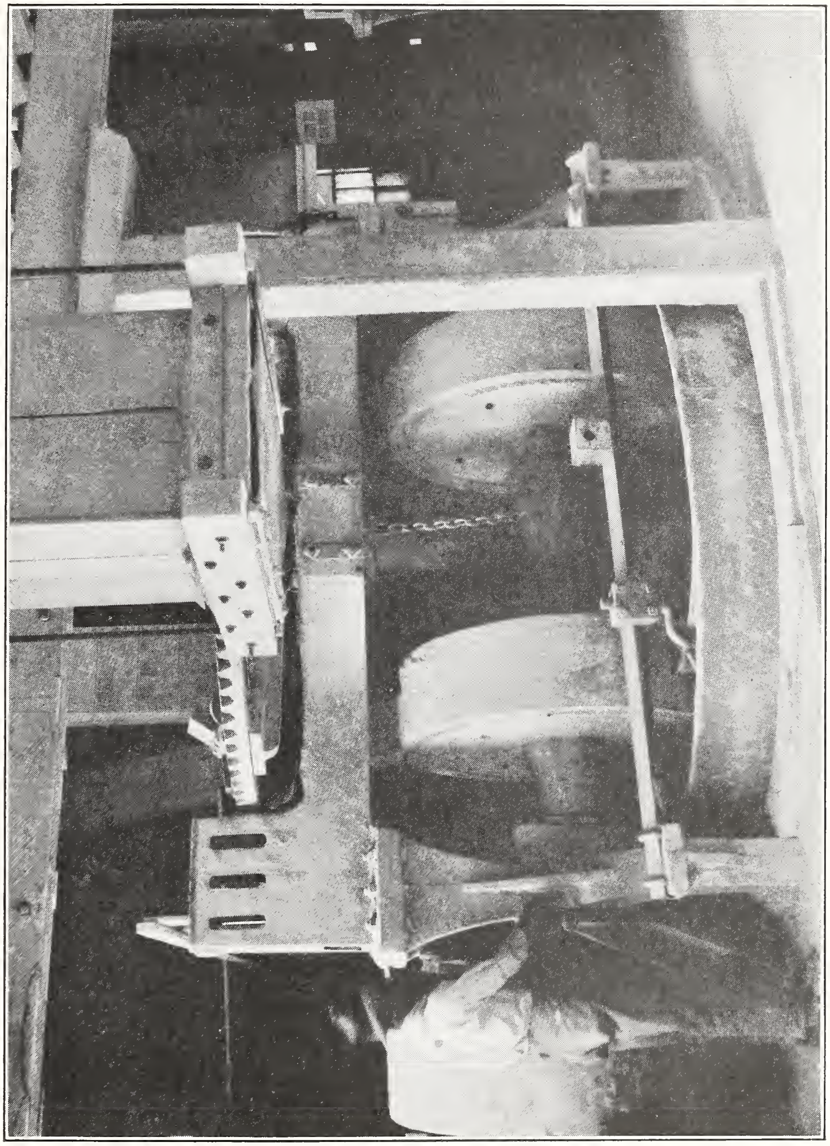
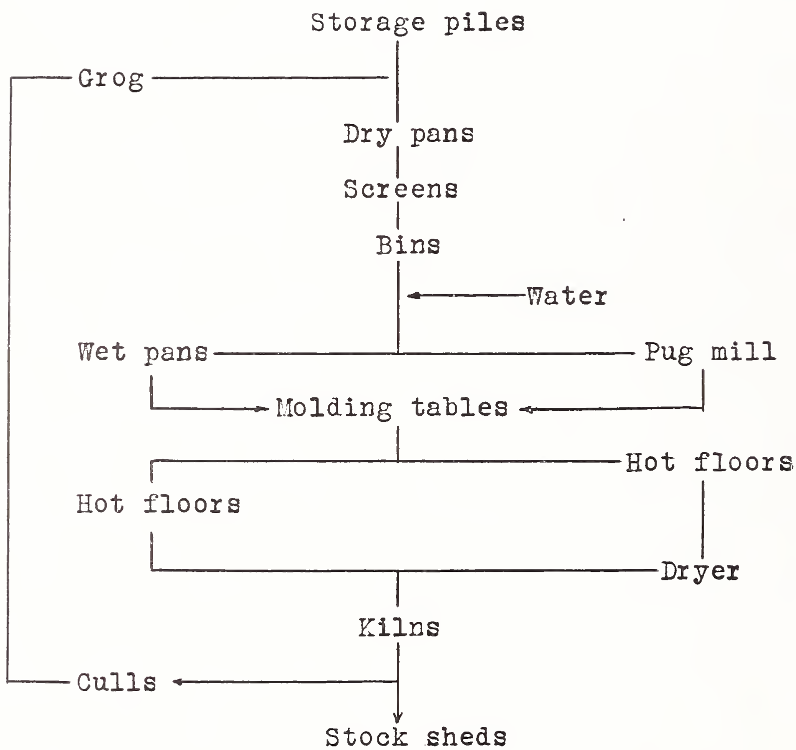


FIG. 12.—*Dry pan used in the grinding of clay and grog*

rial fed to the pan is crushed under the mullers and, when sufficiently fine, sifts through screens or slots either in the outer portion of the pan bottom or in the side. It is then elevated and taken by gravity to the screens and from the screens to the bins.

The next step in the process is to "temper" the ground material with water. The flint clay and plastic clay (as well as the grog and silica,[16] if used) are fed to a wet pan in measured quantities and thoroughly mixed with sufficient water to bring the batch to



Flow sheet No. 1

the proper working consistency. This consistency is usually such that the plastic mass can just barely maintain its shape under its own weight.

A wet pan is essentially the same as a dry pan, except that the pan proper is solid and the tempered mass is removed by mechanical or hand-operated shovels. Figure 13 shows a charge of tempered clay being removed from the wet pan at *A*, loaded on a belt conveyer, and at *B* placed on barrows to be taken to the working tables.

---

[16] Added as sand or ground quartz. In the handmade process a stiffer clay mix is sometimes used, in which case the "wad" is formed by extrusion of the tempered clay in a more or less regular shaped bar.

The tempering process requires from 5 to 10 minutes, and a 9-foot pan has an average capacity (or output) of 3½ tons per hour.

The tempered clay is delivered to the working table (*A*, figs. 14 and 15), where the molder gathers a mass approximately sufficient to make the desired shape and forms it into a wad of such shape as experience has shown to be best suited for throwing into and filling the mold. This process is illustrated at *A* in Figure 14, and in plant parlance is known as "rolling the wauk." It is an important part of the process, for an improperly prepared wad may produce laminations and sand cracks in the finished product, the latter being

FIG. 13.—*Wet pan in which the mixtures of clay, grog, and other materials which may be used in the manufacture of brick are ground and tempered with water to a plastic mass*

caused by inclusions of the sand which is used on the table to prevent sticking.

The wad is next thrown forcibly into a wooden mold (*B*, fig. 14) and the mold "bumped" (*B*, fig. 15) to fill the corners, the excess clay cut off with a "bow," the top surface of the clay slicked or smoothed, and then taken by the "off-bearer" to the hot floor (*C*, fig. 15).[17] For large shapes the molds are single or double, while for 9-inch brick "gang molds" of four compartments are used. The molds must be sanded or oiled to prevent sticking, and this is done by the off-bearer before returning them to the molder.

[17] In many plants all but the largest shapes are dumped from the mold to a pallet and placed directly on rack cars and run into the dryer.

More care is exercised in preparing the batch for refractories used in the manufacture of glass. The ground clay is blunged or mixed with water to a thin slip, run over a magnetic separator to remove

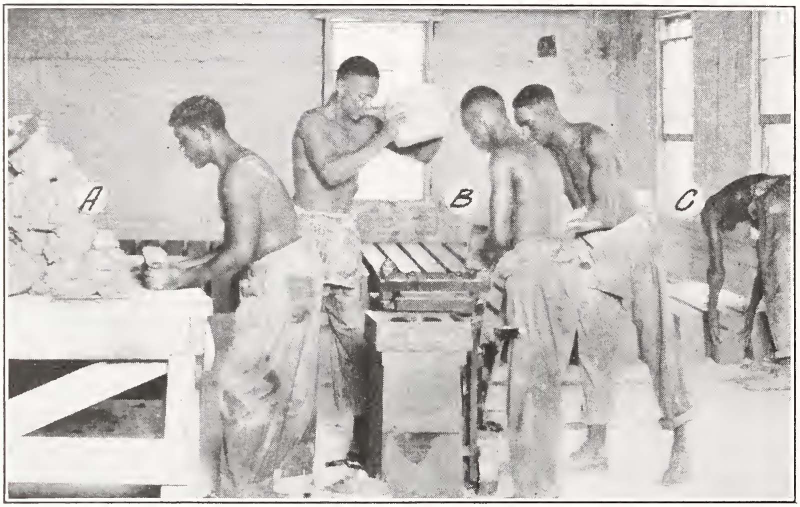


Fig. 14.—*Forming of brick by hand*

mechanically-held iron, filter pressed to remove the inherent soluble salts taken up by the "blunger water," and the filter press cakes taken to the wet pan or pug mill, from which point the regular

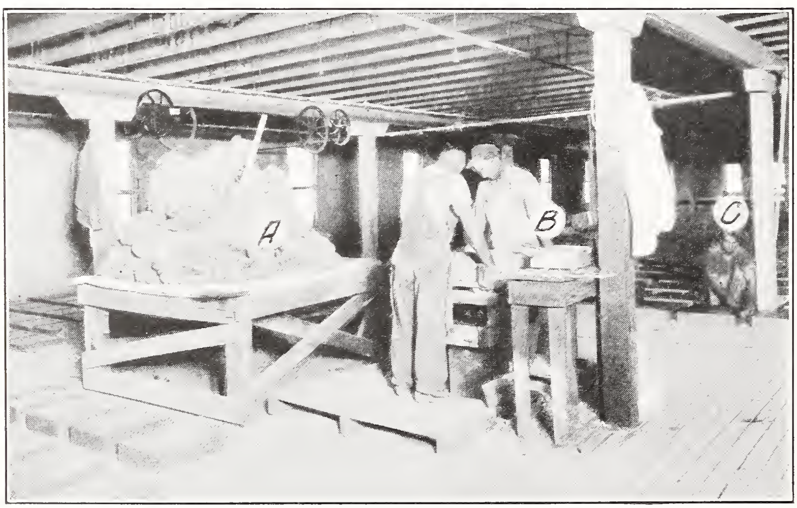
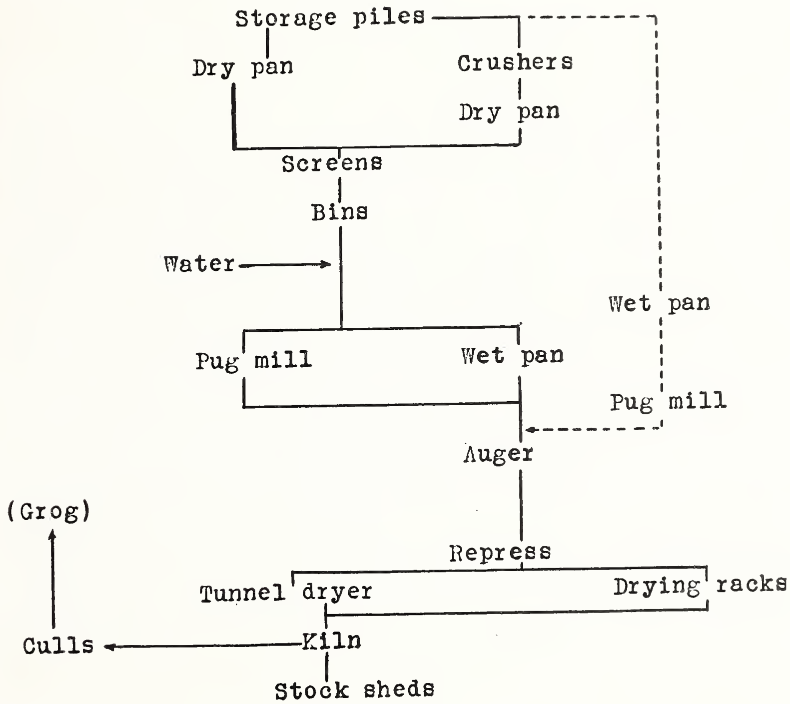


Fig. 15.—*Forming of special shapes by the handmade method*

handmade process is continued. Some plants are introducing shapers, which grind the tank block, either in the dry or burned state, to accurate size.

An alternate method of forming 9-inch brick is illustrated at *B* in Figure 14. The wad is thrown into a hand press, given a slight pressing in a steel mold, which also brands the brick, and is then placed on the hot floor to dry (*C*, fig. 14). A press of the same type as used in this method is also used to repress the 9-inch brick made in the gang molds by the first described or "slop method." In this case the brick are repressed to true the corners and branded after about six hours drying on the hot floor.



Flow sheet No. 2

The generally accepted day's work for a molder and his gang (one molder and two off-bearers) is one thousand 9-inch brick or their equivalent, although they often turn out about 1,500.

(*b*) Stiff-Mud Process.—The stiff-mud process is used very extensively in the manufacture of 9-inch brick. Flow sheet No. 2 is typical.

The process of grinding, screening, and storage in bins is the same as in the handmade process. A few plants, however, using clays which weather or slake down readily, run the clay from the storage piles directly to a wet pan and from there to the pug mill. In this case the clay, grog, and sand (if used) are ground and tempered in the wet pan.

61611°—26†——4

If the materials are first ground and screened, the tempering can be done either in a wet pan or in a pug mill. A pug mill consists of a horizontal iron trough about 14 feet long, containing one or two shafts carrying sets of knives. The clay and water are added at one end and slowly worked to the opposite end, meanwhile being thoroughly kneaded into a homogeneous, plastic mass. The mixture is then discharged into the auger machine.

Whether the water and clay are tempered in a wet pan, pug mill, or (as will be described later for the dry-press process) in a mixer, it is of the utmost importance that the final water content be kept practically uniform. Automatic devices, called poidometers, for

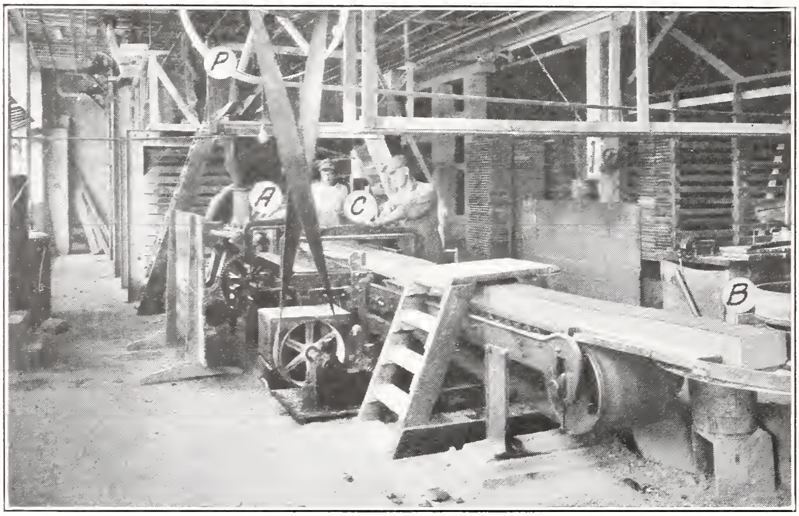


Fig. 16.—*Formation of brick by the stiff-mud method, showing the pug mill which is used to temper the clay, the auger machine, and the cutting table on which the column of clay is cut into blanks*

maintaining uniform mixtures of batch materials have been developed but have not as yet been generally adopted.

The clay for "stiff-mud" brick is mixed with water to such a consistency that the tempered mass can easily be molded by hand into a compact ball, it being neither too stiff to crack in the process nor so thin that it will stick to the hand or ooze out through the fingers.

The auger machine is the "brick machine" proper, for it is here that the clay mass is compressed and formed, by extrusion, into a column from which sections are cut into rough brick called "blanks." The entire process is illustrated in Figure 16. At *P* the pug mill is kneading and tempering the clay-water mixture and is discharging it into the auger machine at *A*. The auger machine can be likened to a huge and complicated sausage machine, the "sausage" being the clay column which is cut into blanks of brick size by the cutter *C*. In practice extreme care must be used in the design of auger blades, worm, and dies, and in the proper lubrication of the clay column in the die to produce a column free from laminations, torn corners, and similar defects.

The freshly cut brick are next carried by belt (*B*, fig. 16) to the repress machine (fig. 17, the auger machine and cutter can be seen in the background at *C*), where men called "pressers" place the brick in the machine. This machine presses the brick in a steel mold and thereby brands them, trues the edges, and presumably forms a dense and compact structure.[18] The repressed brick are delivered by the

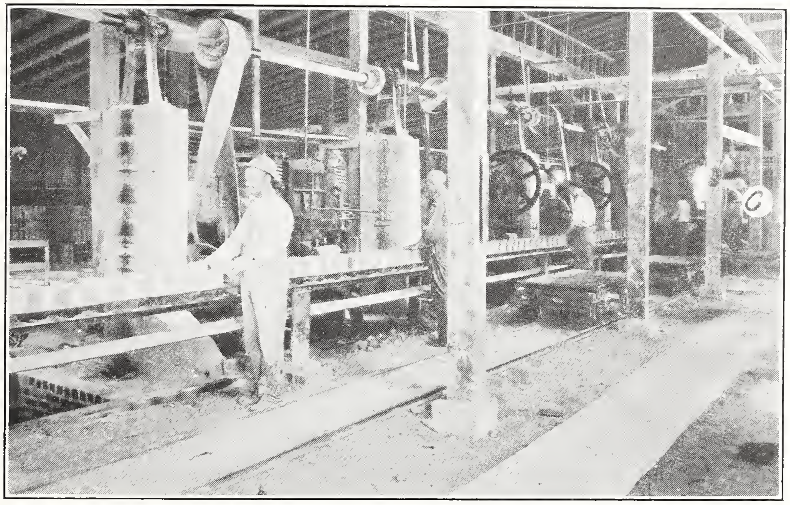


Fig. 17.—*The repressing of the clay blanks from the auger machine*

machine at the opposite side, where "hackers" load them on cars preparatory to drying.

In practice, one machine (pressing two brick at a time) will repress from 1,800 to 3,400 brick per hour, depending on whether a relatively slow or rapid application of the pressure is desired. The pressure is usually applied against the 9 by 4½ inch face, although "edge pressing" has been and is being used. In this case pressure is applied against the 9 by 2½ inch face.

An intermediate step between the cutter and the repress has recently been introduced in a few plants. This consists of sizing the brick by means of knives or revolving blades much like a wood plane. The object is to produce a final product more nearly uniform in size.

[18] By using the proper dies and the proper distance between wires on the cutter the machine will also form the various brick of the 9-inch series, such as arch, key, wedge, and soap, from the same size column.

(*c*) Soft-Mud Process.—This process is not generally used. The brick so made are usually dense and hard, the raw material being wholly or principally a plastic or semiplastic clay and the consistency of the tempered clay mass relatively soft, as the name would indicate.[19]

The process involves dry-pan grinding, pugging, and machine forming of the brick without repressing. The method, while mechanical, is essentially the same as illustrated in Figure 14. A recently developed soft-brick machine (fig. 18) will make from 4,000 to 5,000 brick per hour. It "sands" the molds, makes the brick, and delivers them on pallets to the dryer cars. Six men are sufficient to supply the clay, tend the machine, and care for the formed brick.

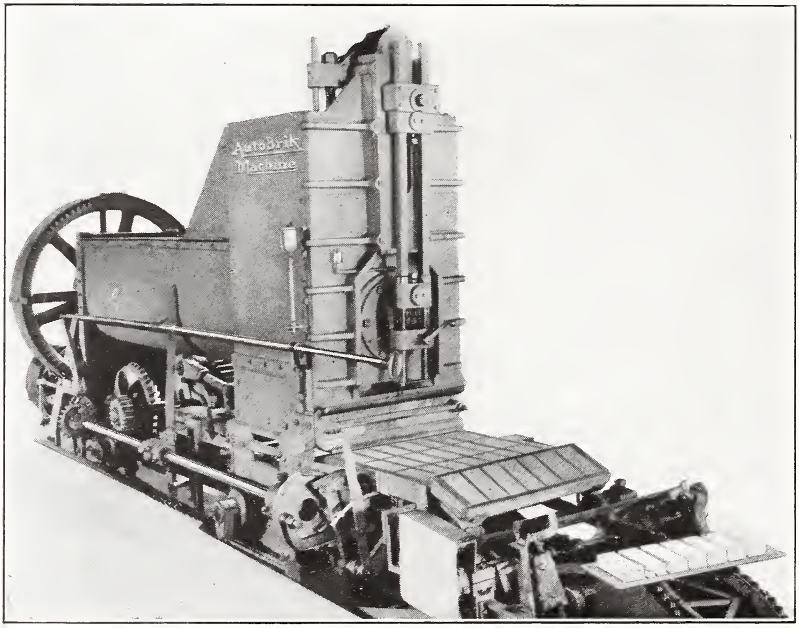


Fig. 18.—*A soft-mud brick machine*

(*d*) Dry-Press Process.—Originally intended for the manufacture of brick from plastic clays, this process has been developed to a point where a successful product can be made using only highly refractory nonplastic flint clay. It has also been adapted to the manufacture of sizes larger than the 9-inch series. A typical plant would operate according to flow sheet No. 3.

In this process the crushing and dry-pan grinding are the same as previously described. The next step is radically different, however, for the clay is not tempered to a plastic consistency, but just enough water is added so that a handful of the mix will retain its shape when

[19] "Manufacture of fire brick by the soft-mud process," by F. B. Allen in the Ceramist, Vol. II, p. 32; 1922.

firmly compressed with the hand.[20] This addition of water takes place in the "mixer," an apparatus usually of the same type as a pug mill but of lighter construction.

From the mixer the relatively dry clay is taken directly to the dry press (fig. 19). Estimates of the pressure under which these brick are formed will vary from 1,000 to 6,000 lbs./in.^{2}, and the number which the machine can make, or at least should make, to produce a good product will vary from 1,000 or less to 2,000 per hour. It is evident that the amount of water used, the pressure, and the time during which the pressure is applied are important factors in the production of a strong, dense brick free from loose corners, "press

```
                      Storage piles
                           |
                        Crusher
                           |
                       Dry pans
                           |
                        Screens
                           |
                         Bins
                           |
                         Mixer <———————— Water [20]
 (Grog)                    |
   ↑                   Dry press
   |                       |
   |                     Dryer
   |                       |
 Culls <———————————————  Kilns
                           ↓
                      Stock shed
```

Flow sheet No. 3

cracks," and other imperfections. However, no definite values seem to have been established for these factors and their relation to the clays used.[21] Figure 19 shows the hackers removing the brick delivered by the press and loading them on cars ready for the dryer.

(*e*) Casting Process.—The casting process is still in the experimental stage so far as its application to the manufacture of shapes from fire clays is concerned. The advantage of the process would lie in the possibility of forming large shapes free from the laminations too often found in the hand-rammed product. These cause serious trouble in service requiring resistance to the attack of liquids as in

[20] Clays usually contain sufficient moisture without the addition of water at the mixer. Several plants, using nonplastic clays, put the mix through a wet pan, allow it to dry out partially, and put it through a dry pan again before pressing.

[21] "Manufacture of refractories by the dry-press method," by Earl Hager, Jour. of Am. Ceramic Soc., **8**, February, 1925.

glass tanks and enamel smelters. Flow sheet No. 4 for this process would probably be typical.

Little is known as yet regarding the best methods to be followed or the relative merits of the product. However, it is doubtful if the process could ever be profitably adapted to the manufacture of other than shapes large in size or intricate in design, and its consideration

```
                          Stock piles
                             |
                            Crusher
                             |
                            Dry pans
                             |
                            Screens
                             |
                            Bins
                             |
Water ---------------------> Blunger
                             |
                            Magnetic separators
                             |
                            Filter presses
        ---------------------|
       v                     |
Grog burned                  |
       |                     |
Reground                     |
       --------------------->|
                            Blunger <---- Deflocculating salts and water.
                             |
                            Casting moulds (plaster of Paris)
                             |
                            Dryers
                             |
                            Kilns
                             v
                            Stock shed
```

Flow sheet No. 4

is not thought to be within the scope of this paper. Those interested can obtain additional information from references in the appendix.

2. DRYING

With the possible exception of some dry-press products [22] all clay brick and shapes can be dried better before being placed in the kilns. Drying is essentially the removal of the shrinkage and pore water.

Shrinkage water is defined as that portion of the water of plasticity [23] which has been driven off when the clay sample reaches the drying stage where shrinkage practically ceases. This is sometimes known as the "leather-hard" condition. In volume the shrinkage water is roughly equivalent to the volume drying shrinkage of the clay.

[22] Department of the Interior, U. S. Geological Survey, Bul. 678. A. B. Searle, Refractory Materials 2d ed., p. 240; 1924.

[23] Water of plasticity (when considered as water tending to produce plasticity rather than as that amount of water required to produce greatest plasticity or "best molding consistency") is designated by the ceramist as that water which can be driven out of a clay in an atmosphere of 4 per cent relative humidity at 110° C.

Pore water is used to designate that portion of the water of plasticity still clinging to the surface of the grains of the clay substance after shrinkage has practically ceased but which may be driven out of the clay in an atmosphere of 4 per cent relative humidity at 110° C. When the pore water has been removed, the clay (or clay body) is said to be "bone-dry."

The shrinkage and pore water, together with the hygroscopic water (retained by absorption and removed in the kiln during "water smoking"), constitute what is known as the mechanically held water.

The removal of the shrinkage water is the critical part of the drying process. During this time the brick or shape is shrinking, and if water is removed from one part faster than from another that part

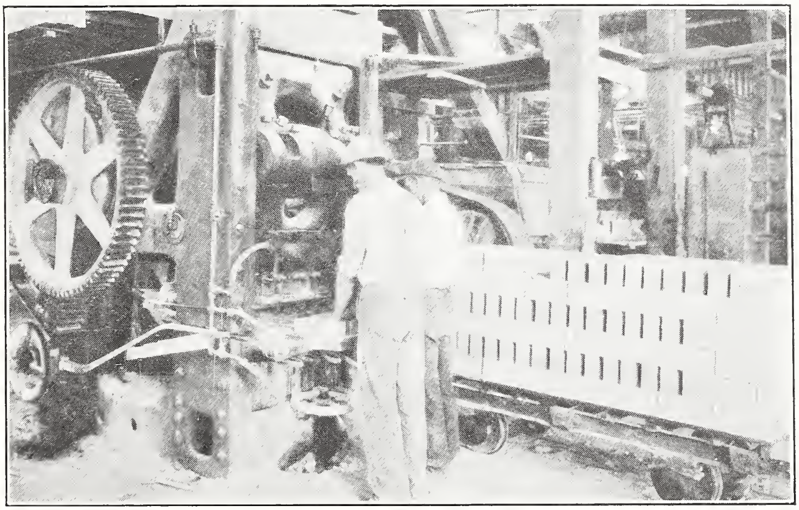


Fig. 19.—*A machine for the manufacture of brick by the dry-press method*

will shrink proportionately. Naturally, this will result in cracks, or at least in strains which are quite apt to cause cracks during the later stages of drying and burning. To obviate such difficulties, the water must be removed from all parts of a unit approximately at the same rate. The care and time required to do this depend on (1) the shape of the unit, (2) the structure of the body, (3) the nature of the clay, and (4) the amount of water to be removed. In brief, drying difficulties increase with every addition of shrinkage water,[24] increase in size, or complication in design.

For example, a brick made by the dry-press process contains practically no shrinkage water, is comparatively small, and is compact.

[24] The shrinkage water required to produce a mix of desired plasticity will be controlled by the amount and plasticity (or "fatness") of the bond clay, which, in turn, largely controls the density of the body to be dried.

Consequently, there are few, if any, drying difficulties. If the shrinkage water is increased, as in a handmade brick, the drying is somewhat more difficult but not serious if even ordinary care is exercised.[25] The next step, increase in size, will not require much additional care in drying if the shapes are dry pressed. However, a large compact shape made by hand must be dried very slowly, for the water should not be removed from the exterior parts of the brick by evaporation faster than it can be replaced by water brought to the surface by capillary attraction. This, in turn, is affected by the denseness of the structure and the type of pores. The higher the percentage of nonplastic clay and grog the more open the pore structure and the

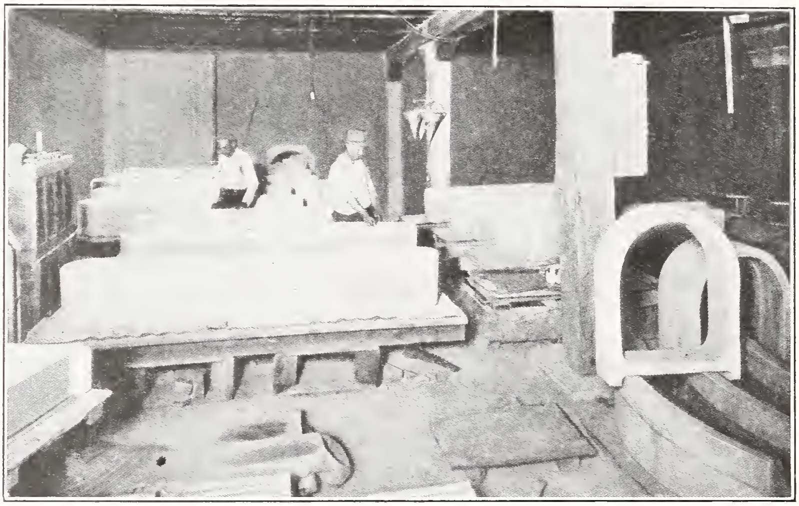


Fig. 20.—*Large, complicated shapes formed by the handmade process*

more easily the water will flow to the surface. The greatest difficulty is experienced with large shapes having flanges, protruding lugs, or other types of design necessitating sharp corners or parts of greatly varying thickness (fig. 20). These shapes often require such special attention as the "protection" of corners with rolls of dense clay or the covering of thin sections with wet cloths, the object being to retard the evaporation of water from the surface while the thicker sections are drying or "catching up" with the thinner ones. It has been found that shapes difficult to dry can often be treated better by the "humidity" system. In this process the entire body of the ware is brought to approximately 50 to 70° C. in an atmosphere so humid that no evaporation can take place (60 to 70 per cent

[25] No trouble should be encountered if the newly formed brick are placed on warm floors and the air kept fairly humid. If, however, the brick are placed on hot floors and in dry air, the clay on the top and sides will lose moisture so rapidly that a crust will be formed, while the heat from the floor will cause the water in the interior to gravitate rapidly to the bottom. Instances have been noted where the tops of the drying brick were leather hard, while the bottom was almost soft enough to flow.

relative humidity). As a result a uniform vapor pressure is created throughout the clay mass and as the relative humidity of the atmosphere is gradually lowered the water is driven out equally from every portion of the shape. This is sometimes referred to as "drying from the inside outward." It requires careful control of both temperature and humidity in the dryer.[26]

(*a*) METHODS.—The simplest and most primitive method of drying was to place the molded brick or shapes in open sheds subject to outdoor atmosphere. This is rarely, if ever, practised in the manufacture of refractories at the present time. The next improvement was to place the units to be dried on floors underlaid with tunnels

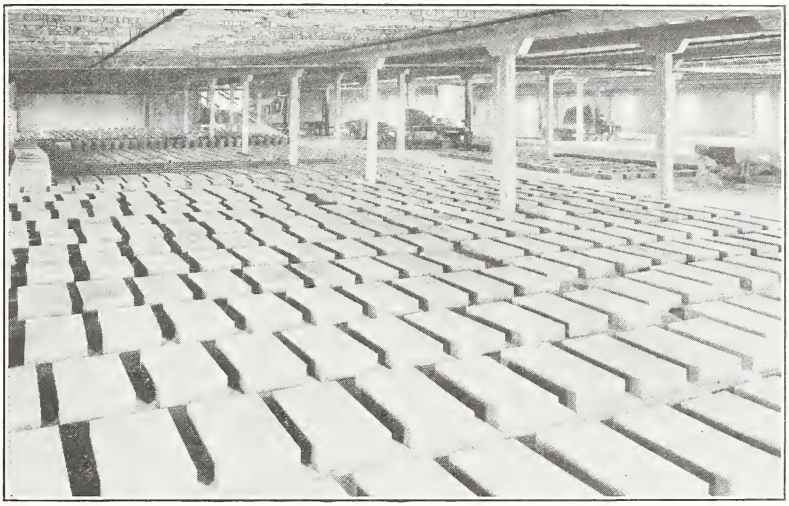


FIG. 21.—*Typical drying floor for brick and shapes*

heated by means of wood or coal. This is not very satisfactory, for it is difficult to distribute the heat properly or to control the temperature.

Modern drying floors (fig. 21) are heated by means of steam, the steam being either exhaust from the engines used for power or generated by special boilers. The floors themselves are usually of concrete, for wood or steel is apt to warp. The concrete slabs are laid over tunnels carrying the steam coils, and provision is made to admit varying amounts of steam under certain sections depending on the heat required. In addition to heating the floors with steam, it is also advisable to provide ducts by means of which warm, moist air can be directed into the drying room when treating shapes which

[26] The following papers contain information on the principles of drying: "Rate of evaporation from solid materials," W. K. Lewis., Jour. Ind. and Chem. Eng., **13**, p. 429. "Theory of atmospheric evaporation," W. H. Carrier, jr., Jour. Ind. and Chem. Eng., **13**, p. 423, 1921. "Ceramic drying and dryers," Stacey and Matzen, Jour Amer. Cer. Soc., 8, p. 525 (1925).

are dried with difficulty. Drying by this method requires from two days to a week.

Probably the most rapid and economical method of drying is by the use of so-called "waste-heat" dryers. They are essentially tunnels which are customarily heated by the waste heat from the kilns,[27] and through which cars carrying the brick are passed (fig. 22). The tunnel dryer is excellent for small, compact shapes, but much better control of the heat distribution and the relative humidity of the atmosphere in the tunnel would be required to dry larger units properly. Drying in tunnels requires from 12 to 48 hours.

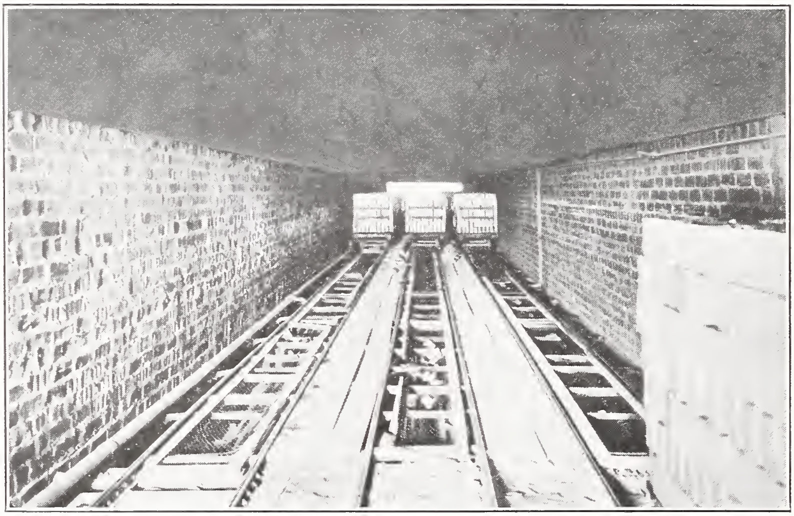


Fig. 22.—*The interior of a drying tunnel showing the cars loaded with brick to be dried and also the steam coils, beneath the tracks from which the heat is derived*

3. BURNING

The definition of brick given in the specifications (VII) states that they are units "which have been burned to produce the desired strength and structure." While the raw materials and the method of their compounding are the primary factors determining the properties of a ceramic product, it is the strength and structure produced by burning which finally determines to what service a brick or shape can be adapted.

The literature is replete with articles describing the various stages of burning, the chemical and physical changes characterizing them, and the effect of time and temperature of burning on the finished product. Since the object of this paper is not to present a discussion of so very complex and highly technical a problem but rather to

[27] Some plants utilize steam for heating the tunnels.

describe briefly methods of burning, the space available will be devoted to a description of the kilns principally used in the fire-brick industry of this country. For those interested in the general study of burning, the "Burning of Clay Wares," by Ellis Lovejoy, is recommended, and also other references given in the appendix.

The kiln most used for burning refractory brick is of the periodic, round, down-draft type and is usually coal fired[28] (fig. 23). The inside diameter will vary from 30 to 42 feet and the capacity from 60,000 to 140,000 brick. With few exceptions a kiln approximately 32 feet in diameter and having a capacity of 80,000 brick is preferred. Burning practice will vary greatly in different plants, but an average schedule would be to water smoke two days, burn from four to six days, and "soak" at the maximum temperature for one-half day. Adding to this the time necessary for cooling, unloading, and reloading it is estimated that the average time of "turnover" on a kiln will be about two and one-half weeks.

The amount of fuel required will vary with the nature of the ware and the efficiency of the installation. Estimates of from 1,500 to 2,400 pounds of coal per 1,000 brick, with an average of from 1,700 to 2,000 pounds per 1,000 brick, were obtained from several large plants. Some of these used natural draft, some forced draft, and some steam (introduced under the grate).

In one type of periodic kiln the draft is furnished by a stack rising from the center of the kiln bottom and extending through the crown. With this construction the burning gases and products of combustion are passed up from the fuel bed over the bag wall or fire box, down through the ware and the floor of the kiln, and then collected by flues running to the stack. The present tendency is to construct a single divided stack designed to serve two (fig. 23) or even four kilns. One decided advantage of this is that the gases from a kiln "under fire" will keep the stack hot and so provide the necessary draft to remove the moisture efficiently from the other kiln or kilns served by the same stack and which are in the water smoking and oxidation stages of burning.

The car-tunnel kiln is probably the nearest approach to theoretically correct construction of any type of kiln developed. It is in accord with the general principle of continuous "straight-line" production and is designed to utilize a maximum of the heat generated for burning. The following objections to its use have somewhat retarded its adoption by the fire-brick industry: (1) Due to the large capacity (average daily output) of the kiln, which is roughly equal to ten 32-foot periodic kilns, an average plant could use only one or two. Consequently, any forced cessation of kiln operation

[28] Gas and oil are also used successfully.

would either seriously interfere with or entirely stop plant production; (2) since the heat balance of the kiln must be accurately adjusted to one particular type of ware in order to operate most efficiently, and most refractory plants make a large variety of shapes and sizes, it does not have at present the desired flexibility; and (3) high initial cost and skill required for operation.

However, tunnel kilns are being used very successfully by at least three manufacturers of refractory brick and shapes. Other than the general advantages already noted there are (1) a material saving in fuel; (2) the comparative ease of setting and unloading facilities production and reduces labor cost; (3) due to better temperature

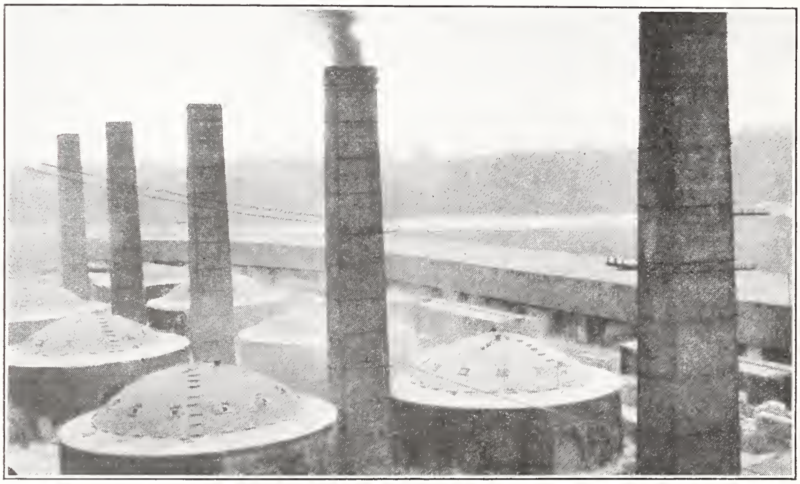


Fig. 23.—*A series of round, down-draft, periodic kilns. Each stack is divided and designed to serve two kilns*

control the time of burning can be reduced, particularly in the preliminary stages, and a more nearly uniform product made as regards shape and structure; and (4) less breakage in the kiln because of the low setting and consequent lighter load on the brick in the bottom tiers.

The details of construction and operation of the tunnel kiln are given in numerous technical articles and industrial magazines.[29]

The continuous-chamber kiln has often been described in the literature, and the principle of construction is indicated in Figure 24. It is essentially a series of periodic rectangular down-draft kilns interconnected by flues. The principal advantage is the conservation of fuel, for when chamber *A* (fig. 24) is under fire the incoming air for combustion is heated by the ware in chamber *C* (which is cooling).

[29] Ceramic Industry, **4,** No. 1, p. 38, January, 1925; C. B. Harrop, The Ceramist, **3,** p. 203, 1924; A. F. Greaves-Walker, Jour. Am. Cer. Soc., **6,** No. 8; 1923.

It then combines with the fuel (gas) in *A*, and the products of combustion give up the greater part of their remaining heat to the freshly "set" (or placed) ware in *B*. Meanwhile dry ware is being set in the chamber to the left of *B*, preparatory to burning, and the burned product is being removed from the chamber to the right of *C*. Only one plant in this country is known to be using the continuous-chamber kiln. It is probably more flexible than the car-tunnel type, but the initial cost is high and very careful design and operation are necessary to insure efficient operation.

In general, present burning practice is not efficient as regards either fuel conservation or uniformity of product. The problem is receiving the attention of industrial, engineering, and technical laboratories, and the construction of better kilns, as well as the controlled burning of

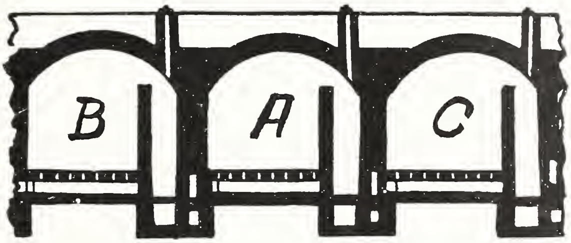


Fig. 24.—*Principles of construction of the chamber kiln*

ware by scientifically developed means along technically correct lines will, no doubt, be justified in the near future by increase in fuel cost and stringency of specifications for the product.

VI. THE FINISHED PRODUCT

1. CLASSIFICATION

The finished product is classified by the manufacturer according to the raw materials used and the method of processing, as follows:[30]

(*a*) Flint-Clay Brick (Shapes), Dry Press, Stiff Mud, or Handmade.—The products of this class are made with flint or semiflint clay, which predominates in the composition, and just enough plastic fire clay to furnish the necessary workability. Typical compositions would be (*a*) 100 per cent semiflint clay, (*b*) 50 per cent semiflint and 50 per cent flint clay, (*c*) 80 per cent flint clay and 20 per cent plastic clay, and (*d*) 100 per cent flint clay.

As indicated in V, under "methods of forming," silica is introduced into some mixes. This is done partly to overcome the shrinkage of the flint and plastic clay and partly to produce a greater rigidity at high temperatures, since silica does not deform at temperatures much below its softening point (approximately 1,635° C.). The use also of

[30] A. V. Bleininger, Liddell's Handbook of Chemical Engineering, pp. 491-493; 1922.

from 10 to 20 per cent of diaspore is being adopted by an increasing number of plants. This is done to increase refractoriness and resistance to the attack of basic slags. The use of silica and diaspore applies to the manufacture of both the flint clay and grog brick and shapes.

(*b*) GROG BRICK (SHAPES), DRY PRESS, STIFF MUD, OR HANDMADE.—The outstanding characteristic of this class is the content of "grog" or preburned material. Since the grog has already been burned, it develops no plasticity when ground, has no drying shrinkage, and practically no further burning shrinkage. Its function in a refractory body is the same as that of aggregate in a concrete mix and, similar to aggregate, the amount and relative size of the particles has an important bearing on the workability of the mix and final qualities of the product.[31] The percentage used will vary from 10 to 60 per cent, the balance being either plastic clay, semiflint clay, or a mixture of plastic and flint clay. Once having determined the amount and fineness of grog best suited to a certain clay, or combination of clays, care should be exercised to maintain these proportions. To simply turn back into the mix such brick or shapes as are rejected after burning, without determining the percentage used or the fineness of grind, must inevitably result in a product varying in size, strength, and structure.[32] Grog is used in practically all large shapes and in many brands of brick, and its continued use under controlled conditions is to be encouraged.

(*c*) PLASTIC-CLAY BRICK (SHAPES), OPEN BURNING, HANDMADE, STIFF MUD, OR SOFT MUD.—This classification is peculiar to products made of silicious clays from the New Jersey district. The clay is sufficiently plastic to be used for bonding purposes, and refractories are made from (*a*) plastic and nonplastic clay alone, (*b*) mixtures of grog and raw clay, (*c*) flint clay (usually from Pennsylvania) and raw silicious clay as the bonding medium, or (*d*) a mixture of grog and flint and silicious clays.

(*d*) PLASTIC-CLAY BRICK, DENSE BURNING, DRY PRESS, STIFF MUD, OR SOFT MUD.—Being made almost entirely of plastic or semiplastic clay, the drying and burning shrinkages are relatively large and the drying and burning proportionately difficult. (This applies particularly to the brick made by the stiff-mud or soft-mud process). Consequently, it is not customary to use such a batch in making anything larger than brick of the 9-inch series.

2. PROPERTIES

(*a*) In general, the chemical compositions and reactions to laboratory tests of flint clay and grog brick are quite similar, as is shown by

[31] B. S. Tech. Paper No. 104, F. A. Kirkpatrick; 1918.

[32] Many plants, particularly in the manufacture of large shapes, do not rely on rejected or reclaimed brick alone for grog, but calcine clay especially for this purpose.

the data in Table 2.[33] The physical structure is also very similar, being determined primarily by the nature of the raw materials [34] (whether relatively pure and open or dense burning) and the method of forming and burning. The use of dense-burning clays, finely ground flint clay or grog, the stiff-mud or dry-press process, and burning to a relatively high temperature (generally cones 6 to 10 or from 1,180 to 1,260° C., and occasionally as high as cone 14, or about 1,380° C.) will result in a product which is dense, hard, and well bonded. This mechanical strength should not, however, be due to a glassy bond; that is, the raw materials should be sufficiently refractory to burn to a dense structure, in the temperature range referred to, without showing incipient fusion.[35] The absorption will range from 4 to 10 per cent.

While a properly bonded dense brick will not only resist abrasion and the penetration of slag but also sudden temperature changes, its production is not always possible with the raw materials at hand. Consequently, to produce a structure resistant to spalling, it is sometimes necessary to raise the absorption at the expense of mechanical strength and resistance to abrasion and slag action. This is done by coarser grinding, lighter burning (cones 2 to 6 or from 1,120 to 1,180° C.), and by using the handmade process. The absorption in this case will range from 10 to 18 per cent. It has also been proven that light-burned brick of the flint clay and grog types show greater deformation under load at high temperatures.[36]

TABLE 2.—*Data obtained in the laboratory on flint clay and grog brick*

District represented	Method of forming	Softening point in cones	Resistance to deformation under load [a]	Absorption	Resistance to spalling [b]	Chemical composition			
						Al_2O_3	SiO_2	Fe_2O_3	TiO_2
			Per cent	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*
Pennsylvania	Handmade	32–33	3.0	9.9	3	43.9	51.2	2.8	-----
	do	33	8.3	10.2	19	41.9	53.8	1.9	-----
	Stiff mud	33	7.8	9.5	59	37.7	58.8	1.9	-----
Kentucky	Handmade	30	9.0	15.0	26	39.8	55.8	2.2	-----
	Dry press	30	4.5	10.6	5	26.8	[c] 70.1	1.7	-----
	do	32	.8	10.5	33	39.9	56.0	1.8	2.3
Missouri	Handmade	32	2.4	11.0	15	35.4	61.1	1.5	-----
	Dry press	33	3.3	8.5	34	48.0	48.2	1.8	-----
	Stiff mud	29–30	2.5	4.1	2	36.6	60.1	2.4	-----
Colorado	Handmade	33+	3.3	18.1	37	77.2	16.8	1.7	3.8
	Dry press	30–31	1.4	9.8	7	31.1	64.0	3.0	1.0
	Stiff mud	31	3.6	7.6	11	28.4	68.1	2.3	1.0

[a] Standard A. S. T. M. load test.
[b] Number of quenchings required to produce failure when quenched from 850° C. to running water.
[c] According to F. S. B. specification (see VII) this would be considered a silicious brick.

[33] For more detailed information, see B. S. Tech. Papers Nos. 7, 159, and 279.

[34] B. S. Tech. Papers Nos. 79 and 144.

[35] When reburning at 1,400° C. for five hours will produce a noticeable amount of glass in a brick structure, data (B. S. Tech. Paper No. 279) indicate that poor resistance to spalling can be expected.

[36] A. V. Bleininger, Jour. Am. Ceramic Soc., **3**, No. 2; 1920.

Table 3.—*Data obtained in the laboratory on open-burning plastic-clay brick of the silicious type*

Method of forming	Softening point in cones	Resistance to deformation under load [1]	Absorption	Resistance to spalling [2]	Chemical composition		
					Al_2O_3	SiO_2	Fe_2O_3
		Per cent	*Per cent*		*Per cent*	*Per cent*	*Per cent*
Handmade	31+	0.70	16.1	13	16.5	82.7	1.1
Do	30	.45	16.1	2	19.0	79.8	1.2
Do	30	.85	15.4	5	20.1	77.9	1.4
Do	31	.28	17.5	5	21.0	77.8	1.2
Do	30–31	1.60	15.1	15	20.4	77.8	1.0
Do	31	.55	17.4	7	22.3	76.5	1.5
Stiff mud	31–32	.35	16.8	13	21.5	76.0	1.1

[1] Standard A. S. T. M. load test.
[2] Number of quenchings required to produce failure when quenched from 850° C. to running water.

Table 4.—*Data obtained in the laboratory on dense-burning plastic-clay brick*

Method of forming	Softening point in cones	Resistance to deformation under load [1]	Absorption	Resistance to spalling [2]	Chemical composition		
					Al_2O_3	SiO_2	Fe_2O_3
		Per cent	*Per cent*		*Per cent*	*Per cent*	*Per cent*
Stiff mud	26−	(3)	11.8	1	26.1	[4] 66.8	3.0
Soft mud	28	[5] 8.4	11.9	2	41.2	51.2	5.6
Stiff mud	27–28	6.5	10.6	5	29.2	[4] 67.3	2.1
Do	26	4.8	10.2	1	33.5	61.1	4.5
Soft mud	26	4.5	17.3	9	24.1	[4] 71.9	2.4

[1] Standard A. S. T. M. load test.
[2] Number of quenchings required to produce failure when quenched from 850° C. to running water.
[3] Complete failure.
[4] According to F. S. B. specification (see VII) this would be considered a silicious brick.
[5] Deformed.

(*b*) Typical compositions of open-burning silicious plastic-clay brick, together with their softening points and behavior in certain laboratory tests, are given in Table 3. Although somewhat lower in refractoriness than the best grades of flint-clay and grog brick, and less resistant to spalling at relatively low temperatures, they do withstand deformation under load better (fig. 25) and also satisfactorily withstand fluctuations in temperature in the higher ranges (above approximately 600° C.).

(*c*) Plastic-clay brick of the dense-burning type are invariably less refractory than those of the flint clay and grog classes (Table 4). This is due to the relatively high content of plastic or semiplastic clays which, as explained in Section IV, contain appreciable quantities of fluxing impurities. The structure is dense and hard, but the actual absorption is often the same as that of a flint-clay or grog brick. The essential difference lies in the fact that the bond of the dense-burning plastic-clay brick is glassy. It will withstand abrasion and deformation under load very well, provided it is not exposed to prolonged heat at temperatures above 1,250 to 1,300° C.; in such service many brick of the plastic type also resist spalling satisfactorily.

3. USES

Refractories are necessary in practically all places where heat is used under control. Certain metallic alloys can be used below 1,000° C.; silica, chrome, magnesite, and other types are particularly adapted to certain work; and special refractories, such as silicon-carbide, fused alumina, zirconium silicate, and others, have their particular purpose, but by far the majority of installations can be built and operated most economically with fire-clay brick and shapes.

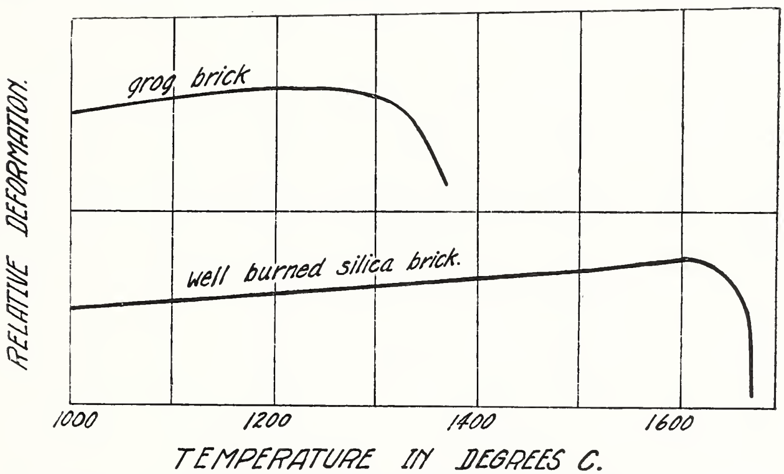


FIG. 25.—*Curves obtained by K. Endell using specimens 5 cm in diameter and 5 cm high under a load of 1 kg/cm² The curve for a silicious brick would probably be very similar to that for a silica brick*

For specific data see p. 121, B. S. Tech. Paper No. 279

The following are some of the more important places where fire-clay, and products made from fire clay, are used: Open-hearth furnaces; blast furnaces; regenerators; ladles for molten metal; crucibles; copper, brass, and bronze furnaces; zinc and lead retorts; ore roasters; coke ovens; lime kilns; cupolas; cement kilns; glass furnaces, tanks, and pots; locomotive arches; pottery, brick, tile, and terra cotta kilns; gas generators; boiler settings; refuse burners; and laboratory equipment.

It is comparatively simple to give a general list of the uses for fire-clay brick and shapes but quite another matter to assign specific uses to brick of a definite class. This is due to the facts that (*a*) the service conditions for a certain type of installation may vary greatly, not only in different installation, but also from time to time in any one installation; (*b*) the information necessary to determine the service conditions is often meager or totally lacking. By this is meant, for example, maximum temperature and average temperature of operation; whether the heat is localized or evenly distributed; amount and range of fluctuation in temperature; amount of superimposed load; speed and temperature of gases through flues and ports; solid and molten materials carried by these gases as well as their possible content of volatilized alkalies; temperature, viscosity, and movement of slags or molten metals; and (*c*) variation in the quality of brick of one brand as well as in brick of the same class but of different brands. It is therefore obvious that an efficient use of refractories necessitates a careful survey of the conditions to which the material will be subjected in service and specifications which will insure a product having the qualifications to meet that service.

The many variables involved have made it extremely difficult to classify types of service. In an endeavor to facilitate such a classification, a special committee of the refractories division of the American Society for Testing Materials and the Refractories Manufacturers Association devised the scheme given in Paragraph VII of the specifications (VII, this circular).[37] Having available a survey of operating conditions, the user can clearly designate by means of this scheme the relative importance of the conditions which a refractory must resist in that particular service.

Various organizations are actively engaged in obtaining a better understanding of service conditions in the industries. When these data are correlated with those already at hand on the qualities of fire-clay refractories it is believed that many of the present refractory problems will be solved.

VII. SPECIFICATIONS

1. HISTORY OF DEVELOPMENT

The first official steps to organize the purchase of refractories by the Government were taken at a preliminary meeting of an interdepartmental conference on refractories held on October 27, 1920. At a second meeting of this committee (attended by representatives of the War, Navy, Interior, and Treasury Departments, the United States Shipping Board, and the Refractories Manufacturers Association) certain definitions and tests were adopted as standard but no action of major importance taken.

Following the meeting of October 27, 1920, the progress of the interdepartmental committee's work was hampered by constant changes in personnel. Practically nothing further was done, and

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[37] See also Report Committee C-8, A. S. T. M. Proceedings, **23**, Pt. I, p. 214; 1923.

the activities of this committee were transferred to the Federal Specifications Board committee on refractories, the organization of which was authorized at a meeting of the executive committee, Federal Specifications Board, held on December 5, 1921. The first meeting of the Federal Specifications Board committee on refractories was called by the chairman, P. H. Bates, on December 19, 1921, but no definite progress was made until the second meeting (March 8, 1922), at which a definite program was outlined comprising a laboratory investigation of the qualities of fire-clay brick and a field survey of service conditions in coal-fired boiler settings.[38] This meeting was attended by representatives of industrial manufactures and users of refractories.

Based largely on data obtained in the investigation outlined at the second meeting, a proposed specification for fire-clay brick was prepared and submitted to the Government and industrial representatives at a third conference called on October 23, 1923. As was to be expected, extensive revisions were made and three more meetings held before the specification was considered as representative of the best information available on the subject. It was finally adopted at the seventh meeting, held on October 20, 1924, almost exactly one year after the presentation of the first draft to the committee.

2. SPECIFICATION

United States Government Master Specification for Fire-Clay Brick

FEDERAL SPECIFICATIONS BOARD SPECIFICATION NO. 268

This specification was officially promulgated by the Federal Specifications Board on January 22, 1925, for the use of the departments and independent establishments of the Government in the purchase of fire-clay brick.

[The latest date on which the technical and inspection requirements of this specification shall become mandatory for all departments and independent establishments of the Government is April 22, 1925. They may be put into effect, however, at any earlier date after promulgation]

I. CLASSES

Fire-clay brick shall be of the following classes: SH 75, H 75, H 57, M 73, H 25, M 7.

For derivation of the class nomenclature used see Section VII of this specification.

II. MATERIAL AND WORKMANSHIP

The material covered by this specification is a brick of standard or special shape composed of heat-resistant clay or clays and which has been burned to produce the desired strength and structure.

[38] B. S. Tech. Paper No. 279.

The brick shall be compact, of homogeneous structure, free from checks, cracks, voids, or soft centers. All corners shall be sufficiently solid and strong to prevent excessive crumbling or chipping when handled.

III. GENERAL REQUIREMENTS

All brick of the standard 9-inch series shall not vary from specified dimensions more than one-eighth inch in width and thickness and three-sixteenths inch in length. For special shapes no dimension shall vary more than 2 per cent from the dimension specified unless greater variation is allowed by contract, but in no case shall a variation of less than one-eighth inch be specified, and they shall be free from such swells, warps, twists, or distortions as shall prevent ready and accurate laying up with a maximum joint of one-eighth inch.

IV. DETAIL REQUIREMENTS [39]

CLASS SH 75.—1. The material shall contain not more than 65 per cent total silica SiO_2.

2. The softening point shall be not less than that of standard pyrometric cone No. 31 (approximately 1,650° C. or 3,000 °F.).

3. The material shall withstand 15 quenchings without failure.

4. When specified the brick shall pass the simulated service test.

CLASS H 75.—1. The softening point shall be not less than that of standard pyrometric cone No. 31 (approximately 1,650° C. or 3,000° F.).

2. The material shall withstand 12 quenchings without failure.

CLASS H 57.—1. The softening point shall be not less than that of standard pyrometric cone No. 31 (approximately 1,650° C. or 3,000° F.).

2. The material shall withstand five quenchings without failure.

3. The absorption after reheating shall be not less than 6 per cent nor more than 16 per cent.

CLASS M 73.—1. The softening point shall be not less than that of standard pyrometric cone No. 29 (approximately 1,610° C. or 2,930° F.).

2. The refractory shall withstand two quenchings without failure.

CLASS H 25.—1. Silicious brick shall contain 70 per cent or more total silica, SiO_2.

2. The softening point shall be not less than that of standard pyrometric cone No. 28 (approximately 1,390° C. or 2,895° F.).

3. The material shall withstand six quenchings without failure.

4. The deformation under load shall not exceed 3 per cent.

CLASS M 7.—1. Silicious brick shall contain 70 per cent or more, total silica, SiO_2.

2. The softening point shall be not less than that of standard pyrometric cone No. 28 (approximately 1,590° C. or 2,895° F.).

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[39] Later determinations yield the following more accurate values: Cone 31 (approximately 1,680° C.); cone 29 (approximately 1,645° C.); cone 28 (approximately 1,615° C).

3. The material shall withstand three quenchings without failure.
4. The deformation under load shall not exceed 4 per cent.

V. METHOD OF TESTING

1. The content of total silica shall be determined by analytical methods described under the A. S. T. M. standard method, serial designation C18–21.

2. The softening point shall be determined according to the A. S. T. M. Standard Method of Test for Softening Point, serial designation C24–20.

3. The quenching test shall be conducted on standard 9-inch straight brick which have been brought uniformly under no load to 1,400° C. (2,552° F.) in not less than five hours and held for five hours and allowed to cool in the kiln and without induced draft to room temperature.

The quenching is conducted in the following manner: The brick is heated by placing in the door of a suitable furnace which is being held at a temperature of 850° C. (1,562° F.). The heated end of the brick should be flush with the inner face of the furnace, and the outer end should be exposed to the free circulation of air. At hourly intervals the hot end of the brick is immersed in running water for three minutes and to a depth of 4 inches. The brick is then removed, allowed to steam in the air for five minutes, and returned to the furnace door. This cycle is repeated until the specimen has failed. The brick is considered to have failed when the entire plane surface of the heated end has completely spalled away, or when the structure of the brick has become so weakened that the end can be easily removed with the fingers. The results of any one brand shall be reported as the average of five specimens.

4. The absorption shall be determined for brick which have been brought uniformly under no load to 1,400° C. in not less than five hours and held for five hours and allowed to cool in the kiln and without induced draft to room temperature.

The test shall be conducted on specimens not less than 100.0 grams in weight, one specimen to be taken from each of five bricks of any one brand and the average result reported. The per cent absorption shall be determined according to the following formula:

$$\text{Per cent absorption} = \frac{W-D}{D}\ 0.100$$

W = weight of specimen after having been boiled in water for two hours and allowed to cool in the water.

D = weight of specimen after having been dried to constant weight at 110° C.

5. The load test shall be conducted according to the A. S. T. M. Standard Method of Test for Heavy-Duty Fire Clay Refractory Material Under Load at High Temperatures, serial designation C16–20.

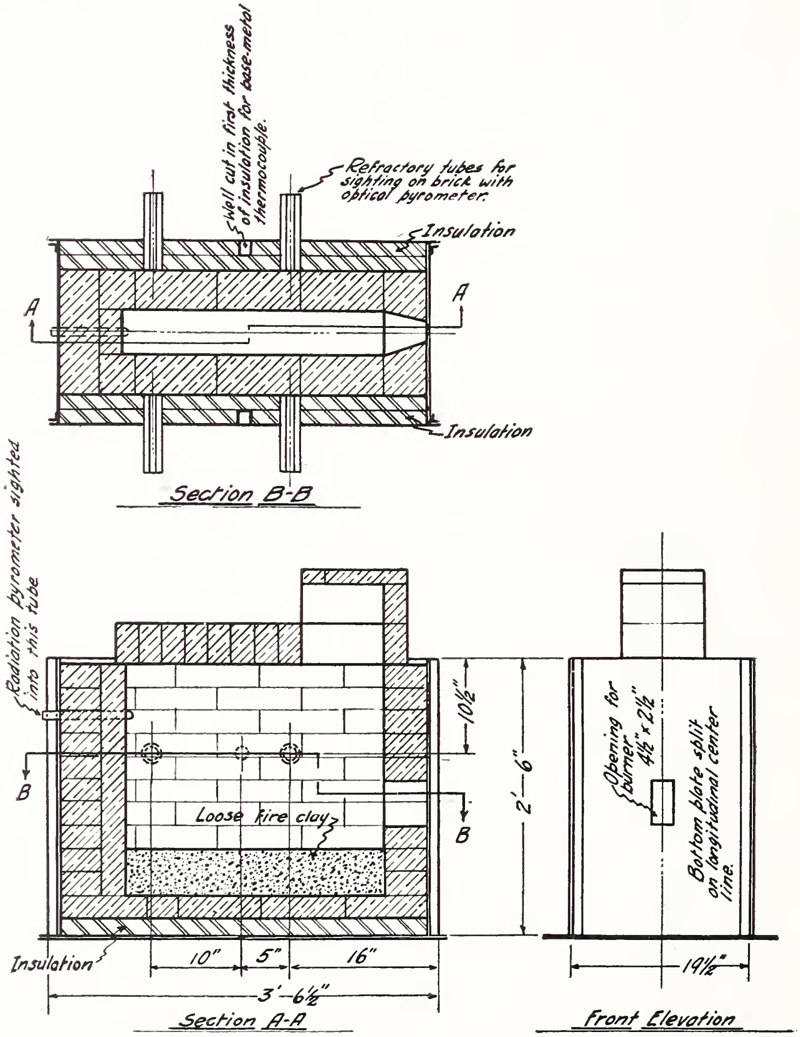

FIG. 26.—*Furnace for conducting simulated service tests on insulating and refractory materials*

6. The simulated service tests shall be conducted in the following manner:

(*a*) Tests are conducted in small oil-fired furnaces, the dimensions and method of construction of which are shown in Figure 26. For comparative purposes one side wall of the combustion chamber is built up of brick and cement of approved brands and the other side wall of brick and cement of the samples under examination. Both walls are backed uniformly with 3 inches of insulation. An air atomizing fuel-oil burner is used. The flame sweeps the length of the furnace, curves upward and returns to the front, then up the stack, from which it escapes horizontally toward the rear of the furnace.

(*b*) The test consists of two runs, each 24 hours' duration, at furnace temperature of 1,590 and 1,650° C. (approximately 2,895 and 3,000° F.), respectively.

(*c*) During each run the following temperature determinations are made:

Furnace temperatures

Temperatures of outer face of brickwork of each side wall at a front and rear of furnace.

(*d*) Furnace temperatures are determined at quarter-hour intervals with an optical pyrometer sighting through front of furnace.

(*e*) Temperatures of the outer face of the brickwork of each side wall are determined at half-hour intervals, with an optical pyrometer sighting on the brickwork through sillimanite tubes, the ends of which are placed flush with the wall. The tubes are carefully lagged and plugged to prevent radiation losses.

(*f*) A spalling test is conducted at the conclusion of each run by injecting air at room temperature under forced draft into the furnace immediately after shutting off the oil supply to the burner. The injection is continued for two hours.

(*g*) The comparative heat insulating properties, together with the relative conditions of the side walls, determined whether or not the material under test is acceptable for use in service.

7. The combined results of workmanship, chemical analyses, softening point, and absorption and load tests, where required, shall be considered as a suitability test, but (at the discretion of the purchaser) the simulative service test may replace all other tests included in the suitability test.

8. Workmanship and softening point determination shall be considered as a control test.

VI. MARKING

In each brick shall be molded the trade name, or the name of the manufacturer, or such a mark as will serve to identify the material.

VII. ADDITIONAL INFORMATION

1. The consignor shall be notified of the rejection of a shipment based on this specification, unless otherwise specified, within 10 days after receipt of a shipment at the point of destination. If the con-

signor desires a retest, he shall notify the consignee within five days of receipt of said notice.

2. The cones referred to in this specification are known as the Orton pyrometric cone.

3. The class nomenclature used in Section I of this specification is based on the following scheme devised by committee C–8 on refractories of the American Society for Testing Materials:

Temperature indicated by prefixing proper letter to number (*H*, high temperature; *M*, moderate temperature; *L*, low temperature)	Load unimportant			Load moderate			Load important		
	Abrasion unimportant	Abrasion moderate	Abrasion important	Abrasion unimportant	Abrasion moderate	Abrasion important	Abrasion unimportant	Abrasion moderate	Abrasion important
Slag action unimportant:									
Spalling unimportant	1	2	3	4	5	6	7	8	9
Spalling moderate	10	11	12	13	14	15	16	17	18
Spalling important	19	20	21	22	23	24	25	26	27
Slag action moderate:									
Spalling unimportant	28	29	30	31	32	33	34	35	36
Spalling moderate	37	38	39	40	41	42	43	44	45
Spalling important	46	47	48	49	50	51	52	53	54
Slag action important:									
Spalling unimportant	55	56	57	58	59	60	61	62	63
Spalling moderate	64	65	66	67	68	69	70	71	72
Spalling important	73	74	75	76	77	78	79	80	81

NOTE.—Class SH 75 (special high temperature) is so designated because it is meant to apply to especially severe boiler practice.

4. Definition of classes—

Class SH 75.—Brick of this class are intended for use under the most severe conditions of boiler practice, such as marine boilers used by the Navy and in plant installations designed to operate at an average rating of not less than 175. Material of this class should have high resistance to slagging, spalling, and severe temperatures. In the United States Navy service brick of class SH 75 are used in oil-fired boilers operated at greater than 500 per cent rating and where severe vibrations and rapid changes in temperature occur. In this service the brick are secured by anchor bolts.

Class H 75.—Brick of this class are intended for use under conditions such as are encountered in general boiler practice. For this class resistance to slagging, spalling, and high temperature is important.

Class H 57.—Brick of this class are intended for use under conditions where resistance to spalling is not of great importance and where resistance to slagging and high temperature is important. In general boiler practice they may be used in the side walls, but if the refractories used are limited to one brand material of class H 75 is recommended.

Class M 73.—Brick of this class are intended for use at moderate temperatures such as are encountered in hand-fired boilers operated at average rating not exceeding 125. Resistance to spalling and slagging is important under these conditions of temperature.

Class H 25.—This class is intended primarily for brick of silicious nature and for service in which resistance to slagging and spalling is not of particular importance but in which the refractory is expected to resist deformation under load at relatively high temperatures. Brick of class H 25 are particularly adapted for service under conditions where resistance to deformation under load, with soaking heats at relatively high temperatures, is important, but where there is no marked fluctuation of temperature below approximately 650° C. (1,202° F.).

NOTE.—Brick of class H75 which withstand the load test satisfactorily may be included in this class.

Class M 7.—This class is intended primarily for brick of silicious nature, for service at moderate temperatures, and under the conditions where resistance to spalling and slagging is not important but where resistance to deformation under load is important. Brick of this class are particularly adapted for service under conditions where resistance to deformation under load, with soaking heats at moderate temperatures, is important but where there is no marked fluctuation of temperature below approximately 650° C. (1,202° F.).

NOTE.—Brick of class M 73 which withstand the load test satisfactorily may be included in this class.

VIII. GENERAL SPECIFICATIONS

No details specified.

VIII. APPENDIX

References to publications relating to fire clay and products made from them. These publications deal principally with properties and methods of testing.

1. Bureau of Standards publications:

SCIENTIFIC PAPERS

S485. Application of the interferometer to measurements of the thermal dilatation of ceramic materials. Price, 5 cents.

TECHNOLOGIC PAPERS

†T7. The testing of clay refractories, with special reference to their load-carrying ability at furnace temperatures.
T10. Melting points of fire brick. Price, 5 cents.
†T17. The function of time in the vitrification of clays.
T21. The dehydration of clays. Price, 5 cents.
†T22. The effect of overfiring upon the structure of clays.
†T51. Use of sodium salts in the purification of clays and in the casting process.
T79. Properties of some European plastic fire clays. Price, 10 cents.
T104. The effect of size of grog in fire-clay bodies. Price, 10 cents.
T144. The properties of American bond clays and their use in graphite crucibles and glass pots. Price, 10 cents.

† Out of print. Can be consulted in leading libraries.

T159. Porosity and volume changes of clay fire bricks at furnace temperatures. Price, 5 cents.

T279. Testing of fire-clay brick with special reference to their use in coal-fired boiler settings. Price, 20 cents.

2. Papers by the staffs of the Bureau of Standards and the Bureau of Mines, which, unless otherwise noted, are published either in the transactions or journals of the American Ceramic Society:

The relation between the porosity and crushing strength of clay products. Trans **12,** 1910.

The behavior of fire bricks under load conditions at a temperature of 1,300° C. Trans., **12,** 1910.

The behavior of fire bricks under load conditions. Trans., **13,** 1911.

The relation between the crushing strength and porosity of clay products. Trans., **14,** 1912.

The melting points of refractory materials. Trans., **15,** 1913.

The relative thermal conductivities of silica and clay refractories. Trans., **16,** 1914.

A method of testing the corrosive action of slag on fire brick. Trans., **18,** 1916.

The effect of size of grog in fire clay bodies. Trans., **19,** 1917.

Prosperity and volume changes of clay fire brick at furnace temperatures. Jour., **1,** No. 6.

*The fusibility of graphite ash and its influence on the refractoriness of bond clay. Jour., **2,** No. 1.

*A machine for testing the hot crushing strength of fire brick. Jour., **2,** No. 8.

Note on the load behavior of aluminous refractories. Jour., **3,** No. 2.

*Behavior of fire brick in malleable furnace bungs. Jour., **3,** No. 7.

*Some properties of refractories. Proc. Electric Furnace Assoc., October 6, 1920.

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* Those marked with a star were published by members of the staff of the Bureau of Mines.

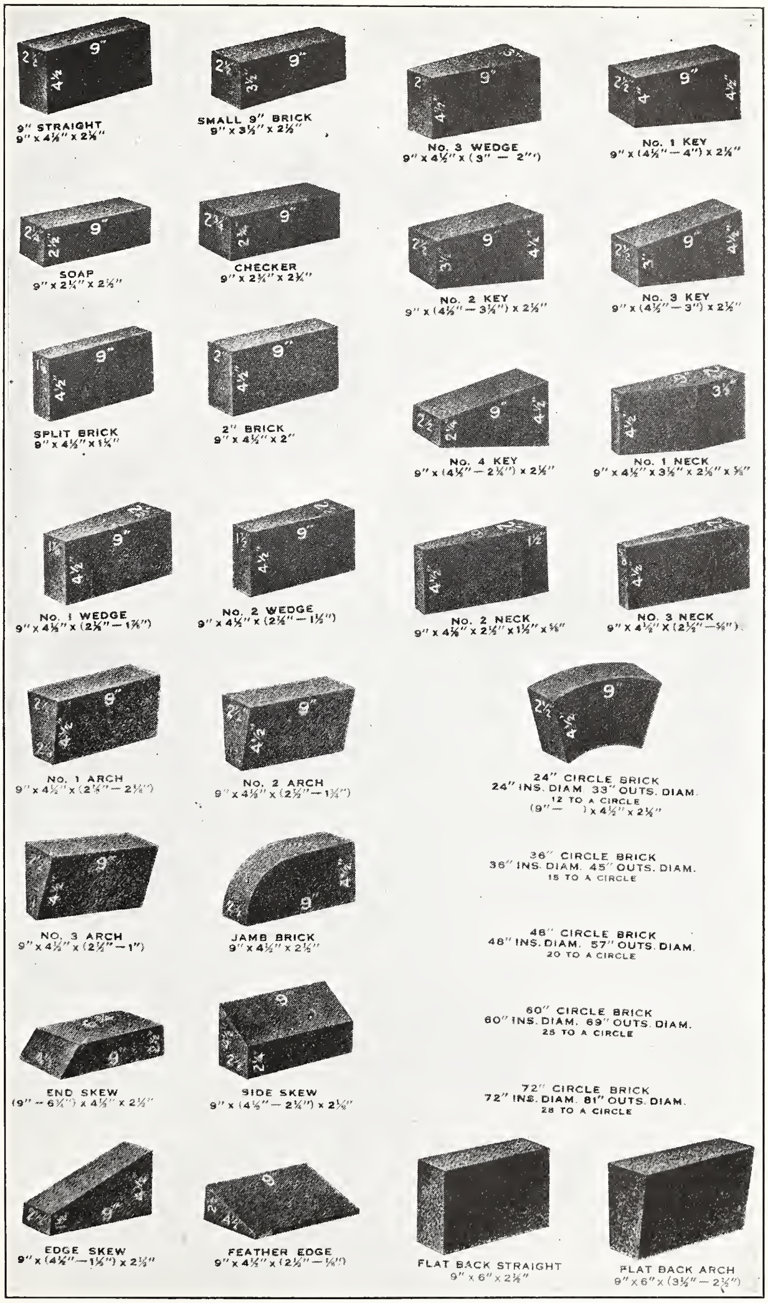

Fig. 27.—*Brick of the 9-inch series adopted as standard by members of the Refractories Manufacturers Association, July 25, 1919*

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WASHINGTON, June 1, 1925.