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# MANUFACTURE AND PROPERTIES OF SAND-LIME BRICK

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# MANUFACTURE AND PROPERTIES OF SAND-LIME BRICK

By Warren E. Emley

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## I. INTRODUCTION

After years of experimenting, fraught with numerous vicissitudes, sand-lime brick has finally achieved a permanent position as a common building material. Putting this industry on a practical paying basis has been beneficial not only to the manufacturers themselves but also to the general public. Almost every citizen has a direct personal interest in building materials. In many parts of the country clay of the quality required to make a good brick is not to be had, and the price which can be obtained for common brick is generally too low to permit of shipping them any great distance. To the people residing in such localities the manufacture of sand-lime brick has been of particular advantage. Sand of a sufficiently good quality is generally abundant, especially in those localities where there is no clay. The ability to make brick of the sand has placed within reach of the users a cheap, durable, noncombustible building material, which is a home product with reasonable transportation costs.

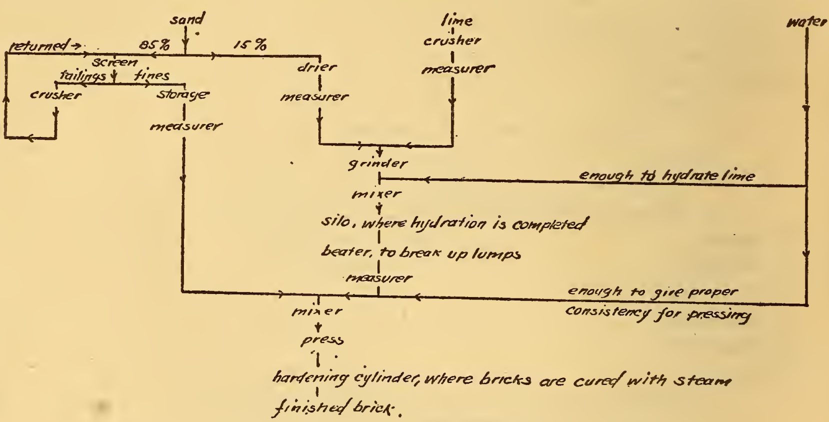


FIG. 1.—*Arrangement of steps in process of manufacture*

## II. HISTORY

The process for making brick of sand was discovered and patented by Dr. William Michaelis in 1880.[1] It is true that Peppel[2] recognizes sand-lime brick made by other processes, and numerous statements may be found in the literature concerning a "sand-lime brick" made in New Jersey about 1860. This material was really a mortar brick, being made of ordinary lime mortar, molded into shape and permitted to set. So far as can be learned, none of these earlier processes has proved a commercial success. All sand-lime brick now marketed in this country are made according to the basic principles covered by the original Michaelis patent.

Dr. Michaelis permitted his patent to lapse without exploitation. Almost immediately thereafter a number of modifications

[1] Process of Manufacture of Artificial Sandstone, DRP, p. 14195; Oct. 5, 1880.
[2] S. V. Peppel, Manufacture of Sand-Lime Brick, Ohio State Geol. Sur., Bull. No. 5; 1905.

were patented, under which the manufacture of sand-lime brick began. These patents, in so far as they covered modifications of the process, have all proven to be of no value and have been generally abandoned. They were of great value to the industry, however, for the attempt to sell the rights to use them aroused and stimulated interest in the subject.

At the present time all the sand-lime brick plants in this country follow the Michaelis process, which is free to anyone who cares to use it. Only a few patents on details of machinery are now in force.

The first plant established in the United States was built at Michigan City, Ind., in 1901 and is still in operation. Since then the industry has grown as shown by the following figures:[3]

| Year. | Total value of product. | Plants operating. | Year. | Total value of product. | Plants operating. |
|---|---|---|---|---|---|
| 1903 | $155,040 | 16 | 1909 | $1,150,580 | 74 |
| 1904 | 463,128 | 57 | 1910 | 1,169,153 | 76 |
| 1905 | 972,064 | 84 | 1911 | 897,664 | 66 |
| 1906 | 1,170,005 | 87 | 1912 | 1,164,984 | 71 |
| 1907 | 1,225,769 | 94 | 1913 | 1,238,325 | 68 |
| 1908 | 1,029,699 | 87 | 1914 | 1,058,512 | .......... |

Almost all sand-lime brick are sold as common building brick, the number of face brick produced being only about 6 per cent of the total. The average price for common brick in 1914 was $5.99 per thousand, f. o. b. cars at the plant.

The history of sand-lime brick manufacture has been largely influenced by the activities of the Sand-Lime Brick Association. This body comprises about 40 members in the United States and Canada. It has been in existence for 12 years and has worked consistently to cheapen the cost and improve the quality of the brick. The annual meetings of the association provide a forum for the discussion of new processes and machinery, they encourage scientific investigation of the product, and are steadily working toward the point where membership in the association will carry with it an assurance of quality of product.

## III. DEFINITION AND DESCRIPTION

Sand-lime brick, as now known to the trade, consists essentially of sand, which is bound together by a hydrated calcium silicate. It has about the same hardness and porosity as common clay

[3] U. S. Geol. Sur., Mineral Resources.

building brick. It is naturally white in color, or nearly so, this being determined by the color of the sand from which it is made, although a few artificially colored sand-lime brick are being sold. The individual specimens are much more nearly uniform in size and shape than clay brick of the same quality. A detailed description of each of the important properties will be found in a later section headed "Tests."

## IV. PROCESS OF MANUFACTURE

The essential steps in the process of making sand-lime brick are: (1) To the sand add the required amount of thoroughly hydrated lime, mixing the two intimately; (2) add enough water to bring the material to such a consistency that it will hold together when molded; (3) press the damp mixture into the desired form; (4) cure the brick by means of steam under pressure. This curing process causes a chemical reaction between the lime and some of the sand to form the calcium silicate, which acts as a bonding agent to hold the rest of the sand together.

## V. CALCIUM SILICATE

Before discussing the raw materials, it would be well to have a clear understanding of the functions which they are expected to perform. The most important function is, of course, the production of the bonding substance upon which the strength of the brick depends.

Michaelis, in his original patent, claimed the formation of silicates which are hard and resistant to the action of air and water by treating a mixture of 10 to 40 parts of the hydroxides of calcium, barium, or strontium and 100 parts of sand or any siliceous material with live steam at a temperature of from 130° to 300° C.

Of course the use of barium or strontium would be too expensive for practical consideration, so that calcium hydroxide, or hydrated lime, is always used. Some siliceous materials other than sand, however, have found a limited application. Among these may be mentioned sandy loam or siliceous clay,[4] volcanic lava,[5] etc. However, sand is by far the principal source of silica used in this country to make sand-lime brick.

The raw materials are thus limited practically to hydrated lime and sand. It will be noted, however, that the patent allows a

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[4] Benson and Herrick, Use of Fine Earths in Mortars, Jour. Ind. and Eng. Chem., 6, p. 796; 1914.
[5] Carmichael, Proc. Sand-Lime Brick Assn.; 1912.

wide variation in the proportions of the ingredients, that the steam pressure used in curing the brick may vary from 5 pounds to over 1000 pounds, and that no definite duration of the steam treatment is specified.

These wide variations of allowable limits would lead one to infer the possible presence of any number of calcium silicates. Common American practice has narrowed these limits, so that the proportion of hydrated lime is seldom over 15 per cent of the sand, the steam pressure may vary from 100 to 150 pounds, and the bricks are cured from 7 to 12 hours. Under these circumstances the evidence seems to indicate that any variation in the strength of the brick is due rather to the quantity than to the kind of silicate produced. Owing to the obstacles encountered in the chemical methods involved, it has been found extremely difficult to isolate this particular calcium silicate, with the result that it has not been subjected to any great amount of scientific investigation. It was formerly believed that most of the bonding material was the monocalcium silicate, some other silicates probably being present.[6] Recently, however, the researches of this Bureau have failed to disclose satisfactory evidence of the presence of any silicate other than the one mentioned.[7] This monocalcium silicate appears to be the only one which can be formed by the action of high-pressure steam upon mixtures of lime and silica, provided, of course, that the silica is in excess. It consists of equimolecular proportions of the ingredients, having the chemical formula $CaO.SiO_2$, and containing 48.25 per cent lime and 51.75 per cent sand. All efforts to obtain this material in a crystalline form have proven failures. It therefore may be considered as a typical amorphous substance, which has the ability to hold indefinite amounts of water in combination with it. Since it is not crystalline, it is impossible to measure any of its optical properties by means of the microscope. Even its index of refraction is not exactly determinable, because this property may vary with the amount of water which the substance contains.

In common with other materials of an amorphous nature, this hydrated calcium silicate can be decomposed rather readily when freshly made, but after drying out it sets in a hard, horny like mass, which is better able to withstand the attack of such reagents as carbon dioxide and water.

[6] Parr and Ernest, Sand-Lime Brick, Bull. No. 18, Ill. State Geol. Sur., p. 62; 1912.

[7] Emley, Klein, and Sanborn, Note on the Silicate Bond in Sand-Lime Brick, Trans. Amer. Ceramic Soc.; 1915.

## VI. RAW MATERIALS

The only two raw materials which have attained commercial importance in the United States are sand and hydrated lime, The former, constituting from 85 to 95 per cent of the weight of the brick, is by far the more important.

### 1. SAND

In selecting a site for the erection of a sand-lime brick plant too much emphasis can not be laid on the quality and cheapness of the sand. A brick is generally considered to weigh about 5 pounds, so that at least 2 tons of sand will be required for every thousand brick made. The cost of this sand may easily make the difference between profit and loss to the manufacturer.

The quality of sand is also of great importance, since this factor may determine the selling price of the brick.

Sands may differ from each other in a number of ways, all of which are important in the manufacture of sand-lime brick. Thus there may be differences in the sizes and shapes of the individual grains and in the amount and kind of the impurities present. The mode of occurrence will influence the design of the factory; that is, whether bank sand, river sand, or sandstone is to be used, and whether the deposit is on land or under water.

Sand has two distinct functions to perform in the manufacture of sand-lime brick, which require different properties of the material. Part of it must enter into chemical combination with the lime to form the calcium-silicate bonding material. The rest of the sand grains constitute the aggregate which is bound together and which forms the main body of the brick.

The common form of silica, quartz sand, is chemically quite inactive at ordinary temperatures. Under the conditions involved in the manufacture of sand-lime brick, it is probable that only the surfaces of the grains are attacked by the lime. The smaller the individual grains the greater will be the surficial area which a given weight of sand will present to the action of the lime. This is evident from the fact that the area of a sphere varies as the square of the diameter, while the volume varies as the cube. It is possible to grind sand so fine that the crystal structure is reduced to an amorphous condition,[8] and under these circumstances the silica has the power to take up water and become quite active chem-

[8] Page and Cushman, Cementing Power of Road Materials, U. S. Dept. of Agr., Bu. of Chem., Bull. 85; 1904.

ically.[9] It is necessary, therefore, that that part of the sand which is expected to combine with the lime shall be in as fine a state of division as possible. If this does not occur naturally, some of the sand must be ground until it is of sufficient fineness. A good practical rule is that about 15 per cent of the sand must pass a 100-mesh screen.[10]

The remaining 85 per cent of the sand is intended to form the inert filler, or main body of the brick. The sizes of grains required for this purpose can obviously be determined by the same rules which are used in proportioning the aggregates for mortars and concretes; that is, the grains should be of assorted sizes, varying from large to small in such a way as to give the greatest density of material. There should be enough fine grains to fill as nearly as possible the interstices between the larger grains.[11] For the greatest strength it is desirable to have the largest grains as large as practicable.[12] The size is limited by the appearance of the brick. It is found that pebbles larger than about one-half inch interfere with the production of sharp corners and are otherwise unsightly.

Screening analyses of a number of sands which are being used in the manufacture of sand-lime brick have been made by this Bureau, with the following results:

TABLE 1

| Location | Per cent by weight retained on sieve No.— | | | | | | Per cent passing sieve No. 200 | Per cent of voids |
|---|---|---|---|---|---|---|---|---|
| | 20 | 40 | 60 | 80 | 100 | 200 | | |
| Savannah, Ga | 1.2 | 28.0 | 56.6 | 3.2 | 7.1 | 2.5 | 1.0 | 45.75 |
| Minneapolis, Minn | .2 | 3.6 | 39.8 | 10.8 | 35.0 | 8.0 | 2.6 | 43.56 |
| Albany, Ga | .1 | 33.0 | 60.8 | 4.8 | 1.2 | .2 | .0 | 43.95 |
| Portage, Wis | .2 | 11.2 | 57.6 | 13.2 | 15.4 | 1.8 | .6 | 48.87 |
| Saginaw, Mich | .6 | 10.6 | 31.4 | 6.0 | 33.0 | 13.4 | 5.0 | 41.68 |
| El Paso, Tex | .1 | 13.2 | 58.0 | 6.2 | 16.0 | 5.2 | 1.3 | 48.52 |
| Flint, Mich | 5.2 | 17.2 | 33.4 | 14.0 | 21.7 | 7.0 | 1.5 | 41.30 |
| Winchester, Ky | 3.4 | 5.6 | 63.6 | 12.4 | 9.8 | 2.4 | 2.8 | 46.72 |
| Rochester, N. Y | 27.0 | 24.0 | 23.2 | 6.8 | 10.8 | 6.8 | 1.4 | 40.35 |
| Buffalo, N. Y | 39.6 | 43.0 | 13.6 | 2.0 | .8 | .4 | .6 | 50.30 |
| Denver, Colo | .0 | .8 | 35.8 | 33.0 | 27.6 | 2.0 | .8 | 42.31 |
| Waltonville, Pa | 19.4 | 19.2 | 30.2 | 9.6 | 12.6 | 6.0 | 3.0 | 41.60 |
| Dayton, Ohio | 48.1 | 32.3 | 13.3 | 2.0 | 2.0 | 1.5 | .8 | 40.87 |
| San Francisco, Cal | 1.0 | 20.6 | 36.8 | 17.4 | 17.4 | 5.4 | 1.4 | 40.65 |

[9] Cushman, Effect of Water on Rock Powders, U. S. Dept. of Agr., Bu. of Chem., Bull. 92; 1905.
[10] Simpson, Proc. Sand-Lime Brick Assn.; 1910.
[11] Burchartz, Luftkalk und Luftkalkmörtel-Mitt. d. Kgl. Material-prufüngsamt; 1908.
[12] Feret, Materiaux des Construction, 1, p. 141.

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Such a great variation in the sizes of grains of the different sands actually used would seem to indicate that this factor is not of particular importance in the selection of sand for making brick. This is undoubtedly true, because at least a part of the sand is almost always ground during the process of manufacture. A sand which is deficient in fine material, therefore, can be made available by grinding some or all of it; but if the amount of fine material is excessive, no remedy can be applied and the brick must be expected to be of poorer quality. It is evident that, provided too much extremely fine material is absent, the size of grain is not an important factor in selecting the sand. Selecting the machinery and designing the plant is, however, of extreme importance, for the greater the deficiency of fine material the more sand will have to be ground before it can be used.

That the sizes of grains of the sand actually entering into the composition of the brick have a marked influence on the strength is shown by the work of Peppel. A preponderance of large grains is conducive to high crushing strength and low transverse strength, while the reverse is true if most of the grains are small.[13]

Care should be taken that the sand selected for the manufacture of brick is reasonably clean. The impurities commonly present are mica, feldspar, and clay. Of these, mica seems to act as an inert filler and its presence in small amounts is not objectionable.[14] Feldspar seems to weaken the brick somewhat,[15] but is mainly objectionable because it is decomposed by the treatment with steam,[16] with the production of soluble alkali salts, which may leach to the surface of the brick and cause efflorescence. Clay up to 10 to 12 per cent is not particularly injurious. It does tend to weaken the brick somewhat, but this effect can be overcome by using a little more lime.[17]

A conclusion based upon the experience of manufacturers is that sharp angular grains give a stronger brick than round ones, because the projections give opportunity for more secure fastening of the bonding material.[18] This factor is hardly of sufficient importance to merit serious consideration.

In some localities it is possible to find deposits of sand which are reasonably clean, free from large pebbles, and dry. If near a

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[13] Peppel, Sand-Lime Brick, Ohio State Geol. Sur., Bull. No. 5, p. 29; 1905.
[14] Rinne, Tonind. Zeit., No. 16, p. 193; 1903.
[15] Peppel, loc. cit., p. 34.
[16] Clarke, Data of Geochemistry, U. S. Geol. Sur., Bull. 330, p. 304; 1908.
[17] Peppel, loc. cit., p. 33.
[18] Simpson, Proc. Sand-Lime Brick Assn.; 1910.

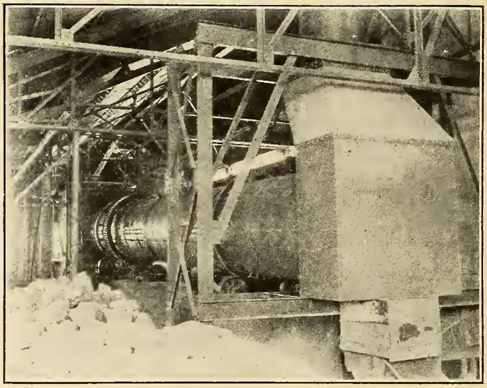

FIG. 2.—*Rotary sand drier*

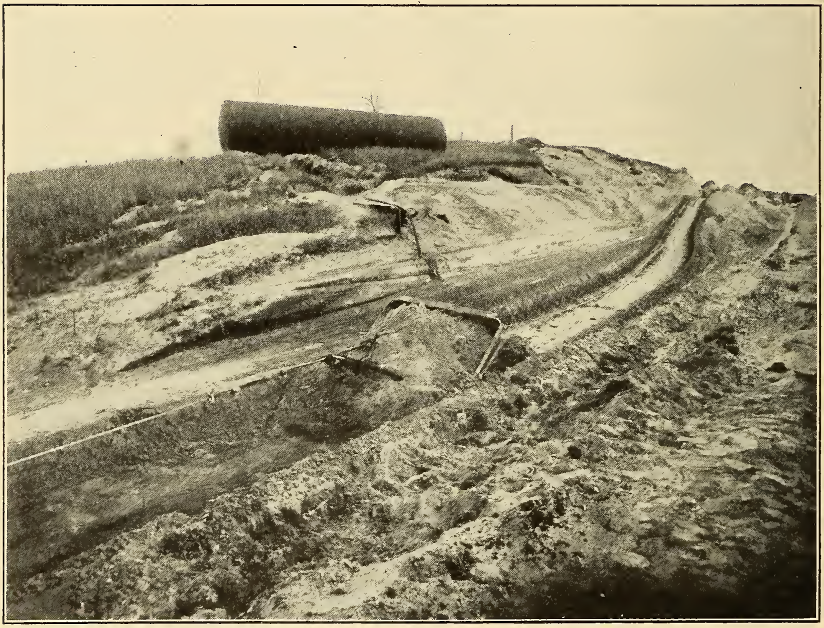

FIG. 3.—*Scraper*

market, these conditions are ideal for the utilization of the deposit for making brick. Of course, all such deposits are frequently wet by rains. This difficulty may be overcome by keeping about a week's supply stored under cover, preferably in the factory. Most of the processes of manufacture now in use do not require that the sand shall be even air dry and a week's storing under a roof, with good ventilation, will dry it sufficiently for the purpose.

It frequently happens that the sand bank contains large pebbles, which must be screened out. For this purpose the revolving "squirrel-cage" screen, so well known in stone-crushing plants, may be used. A cheaper screen and one which requires no power is made of heavy piano wire stretched lengthwise across an inclined frame. The wires are generally placed from one-half to five-eighths of an inch apart. If the market is good, the pebbles may be sold directly as screened gravel. They may also be crushed and added to the sand. A small jaw or gyratory crusher is generally used for this purpose and is also available for reworking broken or poorly made bricks.

Where a natural sandstone is quarried for building purposes, a number of spawls, unsound blocks, and similar refuse soon accumulate in the quarry. Ordinarily this material must be hauled away and dumped. It can be crushed and utilized for the manufacture of sand-lime brick. The extra cost for crushing should be offset against the expense otherwise necessary to keep the quarry clean. The crushing is generally carried out in two stages: The stone is first broken coarsely by a large jaw, roll, or gyratory crusher, and then ground to the required degree of fineness by an impact mill or tube mill.

It is sometimes economically possible to use a sand which is found under water. This can be handled by a centrifugal dredging pump. Even after the excess water has drained off it is generally necessary to dry the sand. This is accomplished by means of a rotary drier using waste steam or some other source of heat if the economic conditions warrant it.

*Delivery of Sand to the Factory.*—The digging of sand from a bank presents no especial difficulties. A crew of men with shovels and wheelbarrows can easily supply any ordinary brick plant. It is never necessary to blast, except when the sand is frozen to a considerable depth. Generally no attempt is made to separate the sand from the surface soil or the strata of loam which it may contain. The roots can be removed by screening, and the argillaceous matter will do no harm if there is not too much of it (not more than about 5 per cent) and if the mixing machinery is efficient.

The factory is almost always located in close proximity to the sand bank. If the distance is very small, the sand may be delivered in wheelbarrows to a bucket elevator, which takes it to the screen.

As the deposit is worked back, the distance from the factory increases until the wheelbarrow is no longer economical. In such cases (which represent a large majority) four methods have been seen in operation: (1) The sand may be shoveled directly into a 2-ton bottom-dump quarry car, which is hauled by cable up an incline to the screen; (2) it may be loaded on wheelbarrows and dumped on a belt conveyor; (3) it may be hauled in by horse and cart, dumping into a bucket elevator; or (4) it may be dragged in by a scraper.

The car and tramway is probably the most expensive of the four to install and takes a considerable amount of power. It is quite flexible; that is, it is a simple matter to lay some new tracks and thus deliver the cars to the particular part of the sand bank where the men are working. It is able to handle large quantities of material quite rapidly and can be extended to work over a considerable area.

The belt conveyor probably can be installed at a smaller first cost and operated with less power than the car and tramway. It is not at all flexible; the sand must be brought to it in wheelbarrows. It would hardly be economical where large quantities of material must be delivered or where the sand is obtained from a large area of ground.

Either of the above methods is probably more economical than the horse and cart. Delivering sand by this system is an extremely slow and laborious process. It is, however, perfectly flexible and requires little initial investment.

The scraper, as used in this industry, is carried by cables and dragged back and forth from the sand bank to the factory. It requires a good deal of power, but has a low first cost, is perfectly flexible, and requires very little labor. The difference in this last item is sufficient to make a decided advantage in favor of this method of handling sand. The scraper not only delivers the sand to the factory, but also digs it and picks up its own load. A plant making 90 000 bricks per day is being supplied with sand by one scraper, which is operated by one man. The machine is not able to deliver the sand any great distance, but it can be arranged to haul to a belt conveyor, which delivers to the factory.

It may sometimes be advisable to locate the factory so that the sand must be shipped to it by freight. This circumstance arises when the sand is some distance from the market for the brick, as it is probably just as cheap to ship the sand in and make the brick near the market as it would be to locate the factory near the sand bank and ship the brick.

The screens are generally placed near the roof of the factory. If the topography and the system of transportation permit, the sand can be delivered directly to the screen. Otherwise it must be carried up by a bucket elevator. The sand which passes through the screen falls in a pile on the floor of the factory, where it is stored until used.

### 2. LIME

Although the proportion of lime used in making sand-lime brick is relatively small, its quality is of paramount importance. The lime must be perfectly hydrated before the bricks are pressed. Otherwise it will expand during the steam treatment and produce internal strains which are frequently sufficient to disrupt the brick. The lime must also be sufficiently caustic to enter readily into combination with the sand.

The factors which influence the quality of a commercial lime are the amount and kind of the impurities which it contains and the temperature at which it has been burned.

The production of underburned lime is due to one or both of two causes: Either the stone was not permitted to remain in the kiln long enough, or else the temperature of the kiln was not sufficiently high to cause complete decomposition. A lump of such lime will contain at its center a piece of undecomposed limestone known technically as "core."

If the lime is not properly handled during the transportation from the kiln to the brick factory, it may air slake; that is, it may take up water and carbon dioxide from the air.

Air-slaked lime is chemically similar to underburned lime, in that each contains more or less calcium carbonate, which may be regarded as an impurity. It is probable that this material is not able to take part in the sand-lime brick reaction (the formation of calcium silicate). It is simply an inert material, whose presence in reasonable amounts is neither deleterious nor advantageous. If the pieces of core in underburned lime are of considerable size, they may be removed by screening the lime after it is hydrated.

The sand-lime brick manufacturer must look upon the presence of calcium carbonate from either source with disfavor, because he must pay for worthless material at the price of good lime, and because he must add a greater quantity of lime in order to get the desired proportion of active constituent in the brick.

Sand and clay are common impurities in lime, but are generally present in such small quantities that they need not be considered, provided that the lime is not overburned. Overburning may be caused by too high a temperature in the kiln or by keeping the lime in the kiln for too long a time. Under these circumstances some of the impurities enter into chemical combination with the lime to form compounds which melt at the temperatures involved. As a result, an impure overburned lime may be considered as being more or less completely vitrified. The product consists of particles of lime whose pores are filled and whose surface is coated with a comparatively resistant glaze. The lime is therefore less able to absorb water and slakes quite slowly. Moreover, the glaze itself, if exposed to the action of water or damp air, will eventually hydrate.[19] The resultant expansion may have quite serious effects on the durability of the brick.

A number of our most important building limes contain large proportions of magnesia, being produced from dolomite instead of limestone. Dolomite contains the carbonates of both magnesium and calcium. Since the former can be decomposed at a much lower temperature than the latter, it follows that by the time calcination is complete the magnesia is badly overburned. The final hydration of such magnesia may require two years,[20] and its tendency to destroy the brick is similar to that displayed by any overburned lime. A process has been patented [21] for making sand-lime brick of dolomitic lime, but has not proven successful. Probably either an overburned lime or a dolomitic lime could be used if sufficient care were taken to insure complete hydration. This has not been found economically possible on account of the length of time involved.

A satisfactory lime for the manufacture of sand-lime brick should be well burned, reasonably free from core and air-slaked lime, and as nearly pure as possible. It is dangerous to use any lime containing more than 5 per cent magnesia, unless especial precautions are taken to insure perfect hydration. Since the lime rarely

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[19] Zimmerman, Pitting of Lime Plaster, Rock Products, p. 42; Apr. 22, 1915.

[20] Campbell, Influence of the Temperature of Burning on the Rate of Hydration of Magnesium Oxide, Jour. Ind. and Eng. Chem., 1, p. 665; 1909.

[21] Brown, U. S. Pat. 697319; 1902.

amounts to 10 per cent of the weight of the product, the difference in cost between a good lime and a poor one is generally negligible. The kind of lime desired is listed as selected high-calcium lump lime in the standard specifications for lime adopted by the American Society for Testing Materials.[22]

*Hydration of the Lime.*—When quicklime is mixed with the water, it slakes to a putty. Lime putty is essentially a mixture of calcium hydroxide with excess water. Calcium hydroxide is a chemical compound containing 75.7 per cent lime and 24.3 per cent water. If the amount is carefully regulated, all water in excess of the above proportions can be eliminated, and the calcium hydroxide is then obtained as a dry flocculent powder. Commercially this material is known as hydrated lime, and the process is called hydration to distinguish it from the production of a putty by slaking. The average specific gravity of 11 samples of high-calcium lime examined in the laboratory is 3.185; the average specific gravity of 7 samples of high-calcium hydrate is 2.343. These figures indicate that lime expands during the process of hydration, the increase in volume being about 80 per cent of the volume of the lime. It is evident that if any of this expansion takes place after the brick is made, serious trouble is apt to occur. One of the most important essentials for the manufacture of a good brick is, therefore, perfect hydration of the lime. In this particular lies the danger of using overburned or dolomitic lime, as noted in the preceding section.

Hydrated lime is a commercial article which is used in large quantities in the building trades. It is therefore possible for the manufacturer of sand-lime brick to buy his lime already hydrated. This is seldom done, however, for two reasons. First, the commercial hydrate is made by a process which has in view plasticity, color, or some similar property of the product, no serious effort being made to obtain perfect hydration. As a result, small proportions of quicklime or of "oxyhydrate" are frequently present. It would not be safe to use the commercial material for making sand-lime brick without taking further precautions to insure complete hydration. The hydrate manufacturer could produce a perfectly hydrated material at little added cost, if there were sufficient demand for it, so that this first reason could be easily eliminated. The second reason why brick manufacturers prefer to hydrate their own lime is economic in its nature and is the determining one. When large quantities of any material are used in an in-

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[22] Year Book, p. 390; 1915.

dustry, good economy demands that the material be bought in as crude a state as possible, providing that expensive equipment is not necessary for refining it. This principle would dictate the purchase of quicklime or, better still, limestone, rather than hydrated lime. The equipment, labor, etc., required to burn the stone is very expensive compared with that necessary for hydrating the lime, so that it has been found most economical to buy quicklime. Other users of hydrated lime prefer to buy it ready-made because of the facility of handling and storing, the saving of labor and time, and other advantages which it possesses over quicklime. Since the commercial article would have to be subsequently treated by the brick manufacturer, in order to insure perfect hydration, most of these advantages would be lost.

For the above reasons brick factories are generally equipped with apparatus for the hydration of lime. This step in the process may be carried out in a number of different ways. The lime may be hydrated either before or after it has been mixed with the sand. The advocates of the latter method claim that a more intimate mixture can be obtained by using perfectly dry quicklime and sand. This is undoubtedly true, especially when the materials are ground together in a tube mill. After the grinding is completed the mass is mixed with the proper amount of water, usually in a pug mill. It is then put in a silo, where it remains for a sufficient length of time to complete the hydration. It is claimed that the heat evolved by the hydration of the lime tends to crack the sand grains and etch their surfaces, so that they are more readily attacked by the lime when subjected to the steam-curing process.

The advocates of "prehydration" (where the lime is hydrated before adding the sand) claim that to use the other method requires that at least a part of the sand must be dried, which is an unnecessary expense. It does seem more logical to make the preparation of the lime an independent step, for it is then possible to remove any unhydrated particles by screening, which can not be done after the sand has been added. At any rate, the manufacturers who prehydrate their lime are in the large majority.

When hydrating a high-calcium lime, particular care must be taken to insure thorough and rapid mixing of the lime and water. Even then it is almost impossible to prevent a very hot lime from "burning itself." This phenomenon may be explained as follows: At the beginning of the slaking process the lime absorbs water. which starts to penetrate toward the center of the lump. Very shortly thereafter the lime on the surface of the lump starts the chemical reaction with the water, which is accompanied by the evolution of heat. Unless especial precautions are taken to insure the presence of plenty of water and to keep it in violent agitation, the heat, which is intensely localized on the surfaces of the lumps, will cause the water to boil and thus inhibit any further absorption before the lime in the interior of the lump has obtained enough water to satisfy its affinity. If the lime is to be hydrated instead of slaked, the amount of water is limited, so that all excess can be evaporated by the heat evolved. In this case the temperature of the mass must rise considerably above the boiling point of water, and frequently gets high enough to cause a partial decomposition of the hydrated lime which has already been formed. The temperature at which this reaction takes place is about 716° F.[23]

In either event the partially hydrated quicklime or the partially decomposed hydrate may be called a calcium oxyhydrate.[24] It is a hard, gritty, yellowish material which shows a tendency to crystallize. It combines with water very slowly, but expands during the reaction. From the point of view of the brick manufacturer it is in the same class as overburned lime and magnesia. It hydrates more readily than either of these substances, so that its presence merely demands extra care in the preparation of the lime, and there is little danger of its causing any trouble in the finished brick.

If sand is added to the lime before hydration, there is not so much danger of burning, because the sand acts as a diluent and tends to prevent rise of temperature by absorbing the heat. It is well, however, to silo the material, so that the reaction may have time for its completion.

There are several machines on the market which are designed to make hydrated lime on a commercial scale. These have not been adapted to the needs of the brick manufacturer; they cost too much and their capacity is greater than he needs. In order to give a reasonable return on the investment, these machines must be run at nearly full capacity, and they would then produce much more hydrate than a brick manufacturer can use.

One method of hydration which is in common use is the "quencher system," which was introduced in 1900 by F. Kom-

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[23] Hursh, Note on the Dissociation of Calcium Hydrate, Trans. Amer. Ceramic Soc., **14**, p. 799; 1912.

[24] Emley, Trans. Natl. Lime Mnfrs. Assn.; 1914.

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nick, of Ebeling, Germany.[25] A quencher is an iron box in the form of a muffle with both ends closed, the flat side being fitted with a removable cover. Into this box is put about 180 pounds of water, followed by 360 pounds of quicklime. (These proportions are subject to variation, depending upon the quality of the lime used.) When the slaking action has apparently ceased, the quencher is found to be nearly full of dry, fluffy powder—hydrated lime. Undoubtedly some of this lime has been burned during hydration. Therefore the quencher and its contents are put in the hardening cylinder, where it fits under the brick trucks. Thus, while the brick are being cured, the hydrated lime is subjected to the action of high-pressure steam. The theory is that this preliminary treatment "takes all of the expansion out of the lime," thus preventing any further action after it has been put in the brick. It is doubtful whether this really occurs. Live steam under high pressure would certainly tend to complete the hydration, but the high pressure is accompanied by a high temperature, the effect of which is directly opposite. At any rate, hydrated lime prepared in this manner contains a great many small, hard particles, which may be the oxyhydrate noted above. Therefore it is necessary to grind the material after hydration. This is generally accomplished by some kind of a hammer mill or similar pulverizing machine. The hydrate is then delivered to the storage bin and is ready for use.

Instead of subjecting the hydrated lime to a steam treatment, storing it in a silo has been found a satisfactory means of insuring complete hydration. The method used is to slake the lime to powder in a quencher or some similar receptacle and dump the material into a silo as soon as the reaction appears to be ended. The powder should be somewhat damp when it is put into the silo, and there should be at least two silos, each large enough to hold a week's supply of lime. Under these circumstances the water will have an opportunity to distribute itself throughout the mass and slake any oxyhydrate which may have been formed during the original slaking. Hydrate prepared in this way is also apt to contain numerous small, hard particles, which may be either oxyhydrate or core. It has been found advisable, therefore, that the hydrate be ground, to some extent at least, before it is put into the brick.

A much better quality of hydrate can be obtained by either of the above methods if the finished product is put through an air

[25] Peppel, Ohio State Geol. Sur., Bull., 5, p. 73.

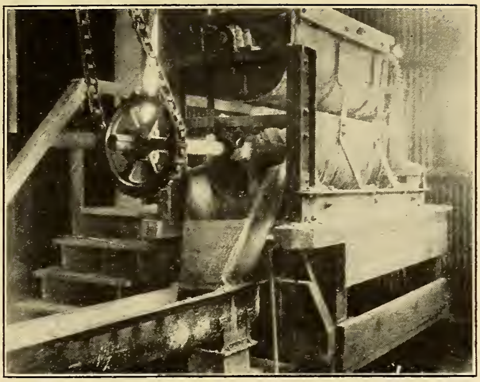

FIG. 4.—*Screw hydrator*

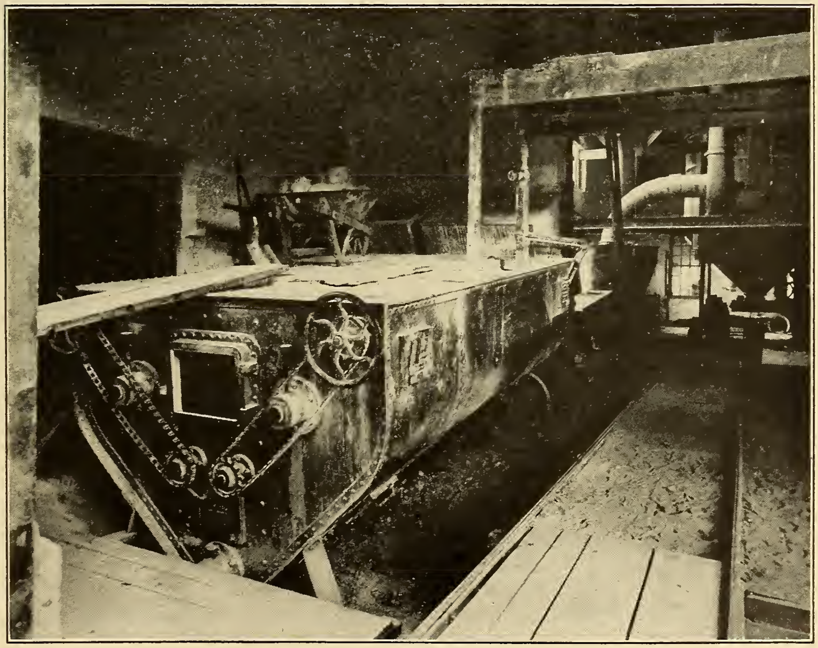

FIG. 5.—*Lime hydrator*

separator. This can be set so as to take out only the very finest of the material for use, the small, hard grains being discarded as waste. This is much safer than grinding them up and mixing them throughout the brick, where they may become the sources of internal strains and weakness.

A hydrating machine has recently been designed especially for the sand-lime brick industry and is now in successful operation. It consists of a pair of cylindrical drums, mounted to rotate on parallel axes which are slightly inclined to the horizontal. The upper ends of the cylinders are closed; the lower ends are fitted with plates which can be moved toward or away from the cylinders by means of screws. From each cylinder is a connection leading to the stack to carry off the steam. A known weight of quicklime is placed in a perforated basket and suspended in the stack in such a way that it is subjected to the steam generated by the preceding batch. It is then dumped into the cylinder by tilting the basket and the proper quantity of water is added from a measuring tank. The cylinder is rotated until hydration is complete, when the plate at the lower end is withdrawn sufficiently to leave a space of about one-fourth of an inch between it and the cylinder. The hydrate flows out through this opening, is picked up by a screw conveyor, and taken to the air separator. Once a day any material, such as core, which will not go through the one-fourth-inch opening, is cleaned out of the cylinder and thrown away. The two cylinders make the machine practically continuous, giving the laborer time to empty and charge one while the other is running. The amount of water and the time required for hydration will vary with each variation in the quality of the lime, so that some slight amount of experience is necessary to be able to operate the machine efficiently.

### 3. PROPORTIONS OF SAND AND LIME

The relative proportions of sand and lime which are used in the manufacture of sand-lime brick are of course very important in determining the properties of the finished product. It will be remembered that Michaelis's patent called for "from 10 to 40 parts of calcium hydroxide to 100 parts of sand." These limits are intentionally broad and very little experimental work has been done to make them more definite. Both laboratory and practical results lead to the general belief that, up to a certain limit, an increase in the proportion of lime will produce a brick of greater strength; but this statement is subject to modification by a great many variables. The pure calcium silicate is a gelatinous material which shrinks on drying in a manner similar to lime paste. In order to obtain a lime mortar of maximum strength, it is necessary to add enough sand to the paste so that the internal strains caused by this shrinking will be largely overcome. Reasoning from this analogy, it is evident that a weak brick can be produced by too much calcium silicate as well as by too little, and the proportions of calcium silicate and sand which are required to produce a brick of maximum strength will depend to some extent upon the quality of the sand, particularly the percentage of voids. Moreover, it is practically impossible to convert into calcium silicate all of the lime which is used in making the brick. Some of it invariably remains as hydroxide or carbonate. The strength of the brick must be considered as dependent upon only that proportion of lime which has been converted to the silicate rather than upon the total lime added. How much of the lime enters into the reaction depends upon a number of factors—the amount of available silica in the sand, the intimacy with which the lime and sand are mixed, the pressure of the steam and duration of the curing, etc. In short, the quality of the brick is influenced by so many other factors that it is a poor criterion for determining the amount of lime to use.

The final decision of this question is based on economy. Lime is much more expensive than sand, so that the general practice is to use as little lime as possible and still obtain the desired quality of brick. How much this will be depends upon the quality of sand and the apparatus used. Each manufacturer is obliged to determine it by actual experiments under his own peculiar conditions.

It is well to bear in mind, however, that a decided increase in the proportion of lime up to a certain limit will result in a decided improvement in the quality of the brick. Of course, it will also increase the cost, but competition with a better grade of material may warrant this. The sand-lime brick manufacturer is fortunate in being thus able to vary the quality of his product to meet the conditions of the local market.

Experience has shown that the effect on the quality of the brick caused by small variations in the proportion of lime is negligible when compared with the effects of other variables, such as thoroughness of mining, water content, molding pressure, etc. Therefore, no very accurate method of measuring the lime has been found necessary. The wheelbarrow or shovel is the unit generally used in practice. The proportions of lime and sand actually put into

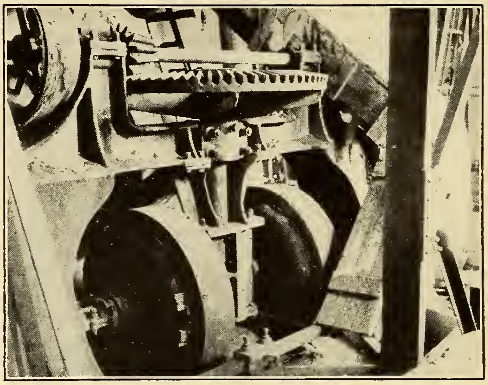

FIG. 6.—*Wet pan*

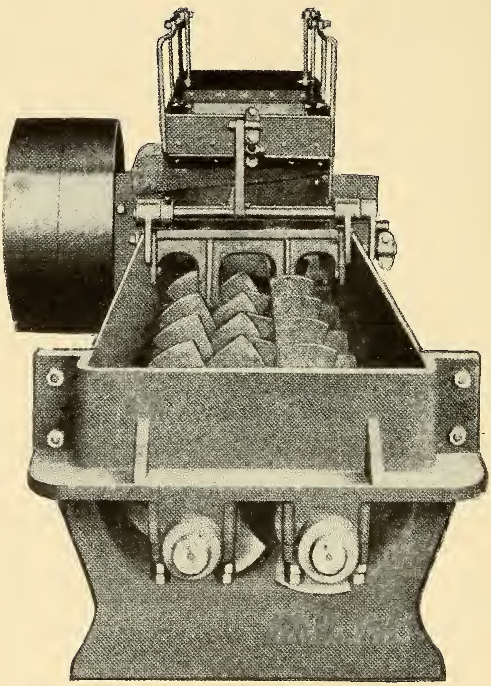

FIG. 7.—*Double screw mixer*

the brick at different factories are usually one shovelful or wheelbarrow load of hydrated lime to four similar volumes of sand. The hydrate is therefore 25 per cent by volume of the sand. Assuming that sand weighs 100 pounds per cubic foot and hydrated lime weighs 40, the hydrate is about 10 per cent by weight of the sand. If the hydrate carries 24 per cent water the above proportions are equivalent to 7.6 parts of quicklime to 100 parts of sand by weight.

## VII. MIXING

Probably the most important step in the manufacture of sand-lime brick is the mixing of the lime and sand. This operation is usually the determining factor in the quality of the brick. Every precaution should be taken that the mixing be thorough and efficient, in order that the best results be obtained from the raw materials at hand. The lime and fine sand should be in intimate contact with each other, so that the chemical reaction between them can readily take place. The coarse sand should be evenly distributed throughout the mass in order that the proportion of voids shall be a minimum.

When part of the sand is ground with the quicklime in a tube mill before hydration, the mixture is about as homogeneous as is reasonably possible. It is then a simple matter to mix in the remainder of the sand. This can be accomplished by means of a pug mill or simply a screw conveyor of sufficient length. However, when lime is hydrated in this way, it is not feasible to screen out the core. Hence, it is generally advantageous to grind the mixture of hydrate and sand as it comes from the silo. This second grinding need not be severe. An impact pulverizer or a dry pan will answer the purpose. Sometimes this grinding is postponed until after the addition of the remainder of the sand, the grinding machine being relied on to mix the ingredients. Under some circumstances this may not be advisable. It may produce too much fine sand to make a good brick.

Where "prehydration" of the lime is practiced, several different conditions must be considered. If the hydrate is not put through an air separator, it should be ground in order to eliminate the small lumps which are inevitably present. Part of the sand may or may not need grinding, depending upon its natural condition. About 15 per cent should pass a 100-mesh screen.

If the sand is of the above fineness and the lime has been put through an air separator, no grinding machinery is necessary; the ingredients need only to be mixed. Two machines are in common use for this purpose—the familiar concrete mixer or the double-screw mixer. This latter machine consists of two screw conveyors mounted on parallel axes in the same trough. They are geared to run in opposite directions and at different speeds.

More frequently, however, it is necessary to grind either the lime or part of the sand or both. If sand is ground in the presence of lime, especially when moist, there is a tendency to develop the amorphous or available silica which is greatly desired.[26] The machine almost always used for this purpose is the wet pan. Common practice is to dump in one barrow of sand and one of lime and grind it for two minutes. Then the remainder of the sand is added and the grinding continued for one minute, when the pan is emptied. This third minute of grinding is detrimental rather than otherwise to the quality of the brick, because, for the reasons previously given, the major portion of the sand should contain a considerable amount of coarse material. However, the wet pan is a very efficient mixing machine, and it is doubtful if the installation of another machine which would mix without grinding would show sufficient improvement in the quality of the brick to be economical. Evidently this is sometimes the case, for a few factories are using a wet pan followed by a double-screw mixer.

A certain amount of water must be added to the mixer in order to hold the brick together while it is being transported from the press to the hardening cylinder. The amount must be rather definite. If too much water is added, the brick can not be properly pressed; if too little, the material is apt to crumble after pressing. The proper consistency is such that the material will just stick together when a handful of it is pressed into a ball. The water is the last ingredient added, either in the pug mill, wet pan, double-screw mixer, or whatever the last mixing machine may be. The quantity is left to the determination of the man in charge, who must make any necessary allowance for the moisture already present in the lime or sand. Final adjustment of the water content can be made in the small agitator which forms an integral part of the press.

It is advisable to provide storage capacity for the mixed material, in order that the presses may be operated independently of the rest of the factory. For this purpose a steel or wooden bin, discharging on to a belt conveyor or a rotating table, is satisfactory.

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[26] Ashley, Chemical Control of Slimes, Trans. Amer. Inst. Mining Eng.; 1910.

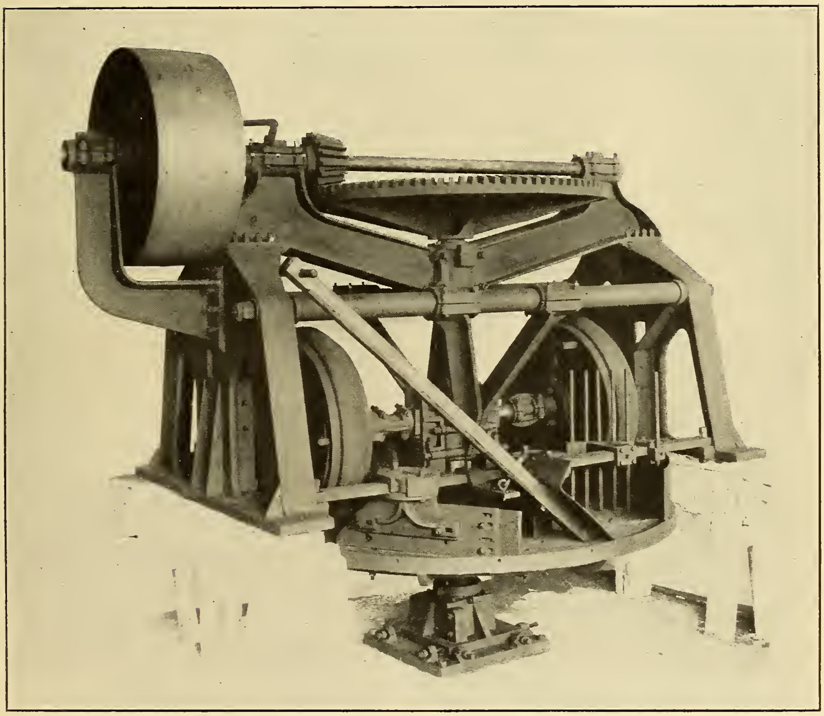

FIG. 8.—*Wet pan (with side removed)*

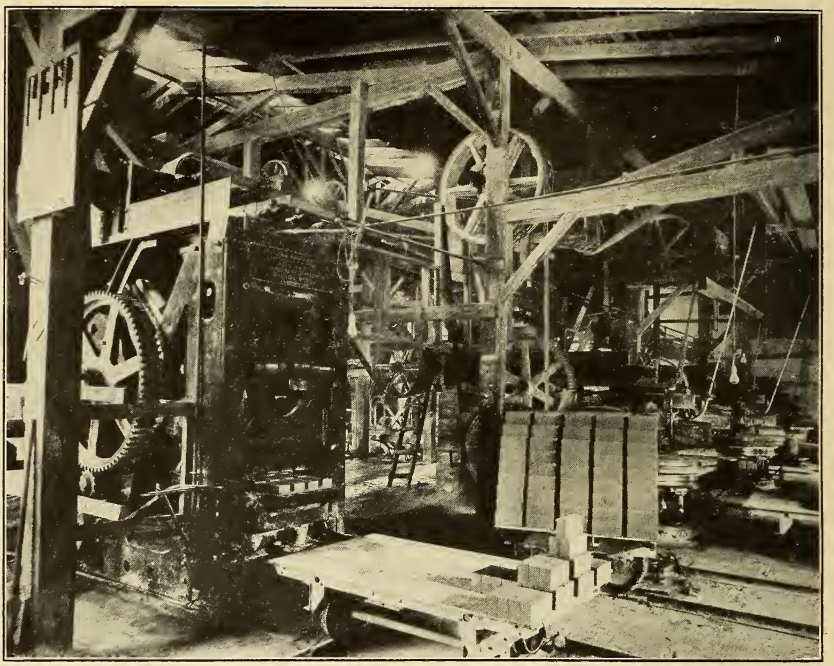

FIG. 9.—*Vertical and rotary presses*

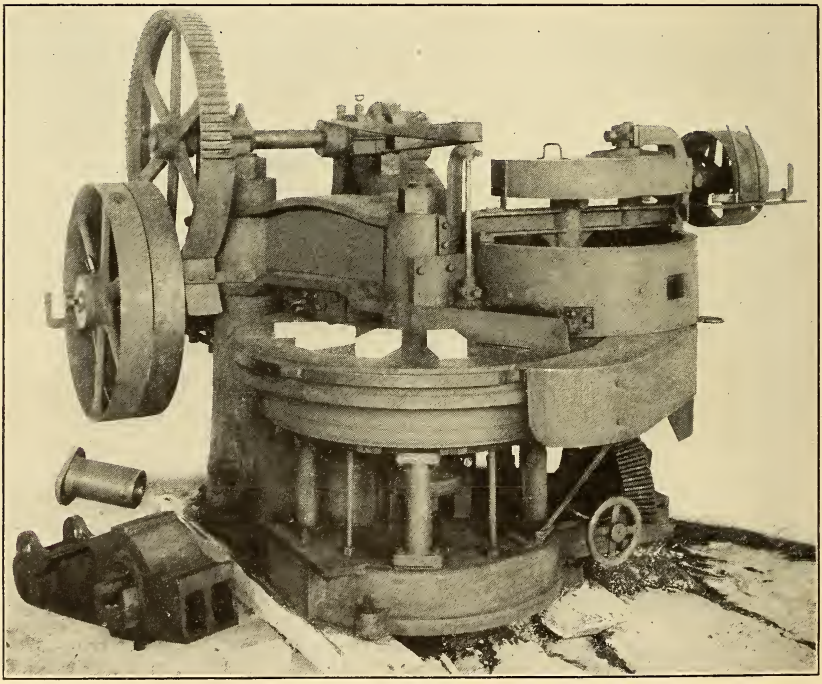

FIG. 10.—*Rotary press*

## VIII. PRESSING

The mixture of lime and sand is now ready to be pressed into the form of a brick. Pressing serves not only to give the brick its final size and shape but performs several more important functions. By bringing the sand and lime into very intimate contact with each other, the chemical combination between them can be facilitated. The compression of the material necessarily decreases the proportion of voids and therefore produces a less porous brick.

The final strength of the brick has been found to depend, to some extent, on the pressure exerted in molding it, and Peppel's results indicate that maximum strength can be obtained by a pressure of 15 000 pounds per square inch.[27] If the bricks are of "Philadelphia standard size" (2⅜ by 4 by 8¼ inches) and are pressed flat, two at a time, 15 000 pounds per square inch would require the exertion of nearly 500 tons' pressure.

Two types of presses are in general use—the vertical and the rotary. The former has found extended use in the clay-brick industry; the latter has been designed more especially for the manufacture of sand-lime brick.[28] The raw material for sand-lime brick differs from clay in some essential features which influence the design of the press. Clay is a soft, plastic material which can be compressed rather easily and which has a tendency to flow under pressure. Sand is hard, gritty, and comparatively incompressible. A sand-lime brick is not subject to any other change of shape or size after it leaves the press, and its uniformity in these particulars is an important point when marketing the product.

In both types of presses the pressure is transmitted through a toggle joint. If the same amount of material is not fed into each mold, the toggle may bend sufficiently to make a noticeable difference in the thickness of the brick.[29] Since it would require an additional pressure of 5000 pounds per square inch to decrease the thickness of the brick two-hundredths of an inch,[30] it is difficult to conceive of a press sufficiently powerful to take care of any inequalities in the quantity of material. An exact regulation of the feeding device would be more logical. On this point the rotary press has been criticized, because the bottom plunger is permitted to drop down by gravity after discharging the brick from the mold. It may occasionally stick, and since the position

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[27] Peppel, loc. cit., p. 44.

[28] Simpson, Rotary Press, Proc. Sand-Lime Brick Assn., p. 60; 1905.

[29] Grath, Vertical Brick Press, Proc. Sand-Lime Brick Assn., p. 96; 1905.

[30] Peppel, loc. cit.

to which it drops regulates the quantity of material entering the mold this may occasionally be less than normal.

Pressure is exerted by the vertical press in two directions, upward and downward; by the rotary press, upward only. It is claimed that pressing on both sides produces a more homogeneous brick.[31]

The abrasive action of the sand on the walls of the die is quite severe. Liner plates of hardened steel, therefore, are provided, which can be readily replaced by new ones. By the rotary press the brick are formed at the top of the die, thus causing less wear of the liners.[32]

The rotary press discharges the brick by pushing it to the surface of the table, whence it is picked by hand. The vertical press pushes it across the table, resulting inevitably in rounding off the lower front edge of the brick.

Either type of press is built in a size to produce about 40 bricks per minute, or 24 000 per 10-hour day.

## IX. HARDENING

The bricks are picked by hand from the press table and piled upon iron trucks. This operation requires considerable care, for at this stage of the process the bricks are very tender and easily crushed in the hand. The trucks are designed to carry about 1100 bricks each. As soon as a truck is loaded it is pushed by hand on tracks into the hardening cylinder.

The receptacle in which the bricks are subjected to the steam treatment may be of almost any size or shape. Common practice has found one style to be satisfactory, so that it is used almost universally. This is a cylindrical shell of open-hearth steel, 70 feet long by 6 feet in diameter, built up of plates five-eighths of an inch thick, riveted together. The shell is set up horizontally and tracks for the cars laid on the bottom of it. The front end is used as a cover and is held in position by 50 nickel-steel bolts 1¾ inches in diameter. After erection the cylinder is tested to a pressure of 225 pounds per square inch.[33] Such a cylinder will hold 20 trucks, carrying 22 000 bricks. The cover of this cylinder is designed to be lifted off by means of a small chain block. A modification lately devised is to put hinges on one side of the

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[31] Penfield, Vertical Press, Proc. Sand-Lime Brick Assn., p. 105; 1905.

[32] Jackson, Rotary Press for the Manufacture of Sand-Lime Brick, Proc. Sand-Lime Brick Assn., p. 177; 1905.

[33] Hartford Steam Boiler & Inspection Co., Specifications for Brick-Hardening Cylinder, Proc. Sand-Lime Brick Assn., p. 169; 1905.

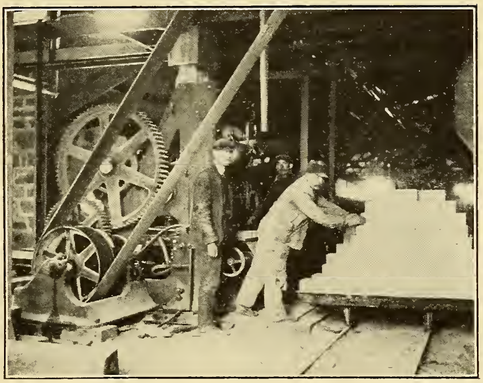

FIG. 11.—*Vertical press*

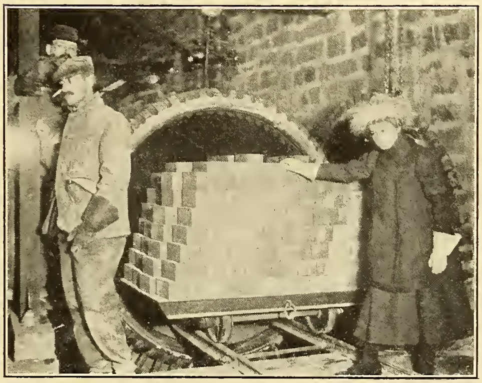

FIG. 12.—*Hardening cylinder*

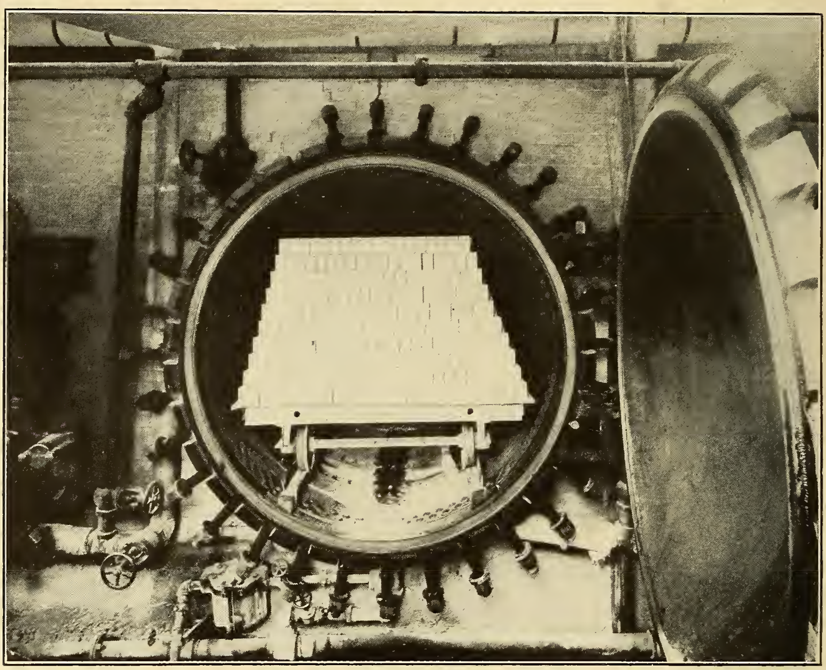

FIG. 13.—*Hardening cylinder with hinged door*

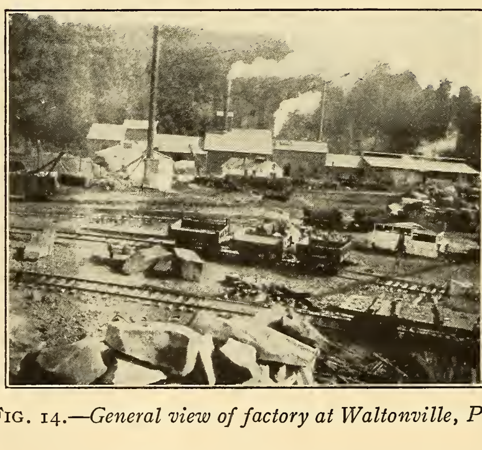

FIG. 14.—*General view of factory at Waltonville, Pa.*

cover, so that it can be opened like a door. This necessitates the use of a better quality of metal, but reduces the number of nickel-steel bolts necessary in the older cover. It thus saves time in opening and closing the cylinder, and also eliminates any danger of the cover falling on the workmen.

The steam pressure used and the duration of the curing process are more or less dependent upon each other. Thus it is optional to use a low pressure for a long time or a high pressure for a short time. Brick have been cured in Germany with steam at 5 pounds pressure for 72 hours, but this is not economical in the United States. It will be noted that one hardening cylinder is about able to take care of the output of one press in 10 hours. Therefore these may be considered as a unit, and one cylinder is required for each press. The press is operated during the day, until the cylinder is filled, and the steam treatment takes place during the night. This results in great economy of boiler capacity, because steam is required either for power or for curing, but never for both at the same time. Since it requires about 3 hours to bring the cylinder up to maximum pressure and about 1 hour to blow off the steam before the cover can be removed, the duration of curing is limited to about 10 hours. Under these circumstances a steam pressure of about 120 pounds per square inch has been found satisfactory.

If it is desired to increase the capacity of the factory, the method just outlined would call for an additional cylinder, press, and boiler. It is possible to obtain the same end by the installation of an additional cylinder and boiler and using the same press for more than 10 hours a day. In this way the old unit is disregarded, the cylinders are operated independently of the press, and the duration of the curing is not subject to the same limitations.

The steam pressure is generally dictated by other considerations—the boiler, engine, and power-plant equipment. The duration of curing should be determined by each manufacturer by actual experiment, for one would expect it to be affected by each variation in the raw material used. Factories may be found in the United States using steam at pressures varying from 100 to 150 pounds per square inch, while the time of curing may be anywhere from 7 to 11 hours at the maximum pressure. Experiment has shown that 4 hours at 150 pounds steam pressure is sufficiently long for making good bricks, while 6 to 8 hours are required at 120 pounds and 8 to 12 hours at 100 pounds.[34]

[34] Peppel, loc. cit., p. 47.

A great deal of steam is required to bring the contents of a cylinder up to maximum pressure. If it can be arranged so that one cylinder is ready to blow off just when another one has been filled, the waste steam from the first can be used to heat the second.

## X. HANDLING

When the trucks are taken out of the hardening cylinder, they should immediately be taken to the loading platform, where the bricks are transferred to freight cars for shipment. If immediate shipment has not been provided for, it may be necessary to store the brick in the yard, but this is very objectionable because the extra handling involved adds about 25 cents per thousand to the cost.

The bricks are generally handled by one of three methods: (1) Passing them by hand from one man to another; (2) the hand carrier, which is built on the principle of a pair of tongs and is capable of picking up 8 or 10 bricks; and (3) the gravity carrier. This is a chute set on small iron legs arranged to give it a slight inclination. The bed of the chute is made up of small wooden rollers, set close together, which are free to turn as the bricks slide over them.

Almost all sand-lime bricks are sold as "common brick." If face brick are desired, they must be selected by hand to make sure that each one is perfect, and they must be packed in straw or some similar material to prevent breakage during transportation.

## XI. PROPERTIES

The size and shape of a sand-lime brick depend entirely upon the size and shape of the die in which it was pressed. The bricks, therefore, are characterized by their remarkably straight edges and plane surfaces. The size can be changed at the will of the manufacturer, but is generally that which is customary for common brick on his local market.

When the bricks leave the hardening cylinder they are saturated with moisture, and are therefore gray in color and have a dead sound when struck. On exposure to the air they soon dry out, the color becoming nearly white and the sound developing into a good ring.

A sand-lime brick is not necessarily white in color, for the sand itself may be highly colored, especially if it is crushed sandstone. Moreover, artificially colored brick are quite common. These are made by the introduction of the necessary pigment during the mixing of the raw materials. The pigment must be of such a nature that it will not be affected by the lime or the steam treatment and must be quite cheap, because a rather large amount of it is required. The pigments generally used are the oxides of iron for red or buff and lampblack for gray.

Sand-lime brick are frequently made with indentations on one side, which are known commonly as "panels." These panels serve two purposes. They enable the mortar to attach itself more firmly, and they reduce the weight of the brick without changing its dimensions. This latter point is of importance because the freight is estimated by weight, so that any reduction in the weight of each brick results in a corresponding reduction of the freight per thousand.

A well-made sand-lime brick when broken will show a uniform texture, with perhaps a few large pebbles scattered throughout it. These pebbles should be so firmly embedded that they can not be removed without breaking. Occasionally minute white spots are found. These generally consist of hydrated lime surrounded by a shell of carbonate, although they may be all carbonate if the brick has been weathered long enough. Their presence indicates either imperfect hydration of the lime or insufficient mixing of the lime and sand, or both. If quite minute and thoroughly scattered throughout the brick, they are of no great importance. They are always accompanied by more or less internal strain, and if they are of any great size, planes of weakness will be found in the brick which may be sufficient to injure its quality.

The strength, porosity, and other similar properties will be found described in a following section headed "Results of tests."

## XII. TESTS

Numerous laboratory tests which could be applied to brick have been devised, originally so that the manufacturer could judge accurately of the quality of his product. Attempts have been made to extend the use of these tests by embodying them in specifications for the use of architects, building inspectors, etc. The tests generally recommended include the determination of the resistance to compression (crushing strength), the resistance to bending (transverse strength), and the amount of water the brick will absorb. The use of such tests in specifications has been severely criticized, because, it is claimed, that the properties measured are unimportant to the purchaser. The purchaser demands primarily that the brick shall have a good appearance when laid in the wall and shall be able to withstand the action of the weather. Any brick which fulfills these conditions will be amply strong enough to stand any load which common engineering practice should design it to carry.[35] The truth of this last statement is open to question. It may be that the strength of a brick is relatively unimportant, but one must not forget that the bricks are actually subjected to transverse and compressive stresses in use. It is certainly necessary to know that they are at least able to withstand the stresses which may reasonably be expected to come upon them. The tests usually made take no cognizance of the appearance of the brick nor of its resistance to weather conditions. As regards strength, it is known that the strength of a brick wall or pier depends more upon the workmanship and the kind of mortar than on the properties of the individual bricks.[36] The advocates of these tests claim that any determination of the actual properties desired in a brick would require so long a time as to be impracticable. The strength of a brick is of but little value in itself, provided, of course, that it is greater than that actually required in use, but is valuable as a means of comparing different bricks. For example, experience has shown that a brick having a certain strength and absorption will satisfactorily withstand the action of the weather, while a brick having lower strength or greater absorption is apt to disintegrate.[37]

The directions for making tests for compressive and transverse strengths and absorption are given in the report of Committee C–3 of the American Society for Testing Materials [38] and need not be described in detail.

### 1. RESULTS OF TESTS.

(*a*) *Crushing Strength.*—The crushing strength of a brick is measured by the load which it is able to support when it is bedded on a flat surface and the load is equally distributed over the top and bottom areas. The results obtained will vary according to the method of conducting the test, which may differ in several important particulars.

The rate at which the load is applied may cause an apparent variation in the crushing strength as measured. If the testing machine is run at high speed, the results are apt to be higher than

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[35] Irvine, Discussion of Brick Specifications, Proc. Sand-Lime Brick Assn., p. 44; 1913.
[36] Griffith and Bragg, Some Tests Upon Large Brick Piers, Clay-Worker, p. 367; March, 1915.
[37] Emley, Analytical Study of Brick Specifications, Proc. Sand-Lime Brick Assn., p. 41; 1913.
[38] Proc. A. S. T. M., p. 282; 1913.

they should be. American practice requires that the load be applied at such a rate that the beam of the testing machine is kept floating.

The surface of a brick is seldom a true plane. It may be slightly warped, it may contain small uneven areas, or it may be paneled. Any one of these conditions would prevent an even distribution of the load over the entire surface of the brick. To eliminate this factor, the brick should be capped in such a way that the two surfaces in contact with the heads of the testing machine are made as nearly plane as possible. The caps may be made of blotting paper, Portland cement, or plaster of paris, the last being preferred in American practice.

The most important factors to be considered are the size and shape of the test piece. By the German method the specimen is prepared by sawing a brick in half and placing one half on top of the other, with a thin joint of neat Portland cement in between.[39] The American practice is to test a half brick capped so as to lie flat in the testing machine,[40] although some advantages are claimed in favor of standing the specimen on edge.[41] Burchartz has cited the principle that the crushing strength of a specimen will vary directly as the square root of its area and inversely as its height.[42] Of course, this can apply only approximately to such a heterogeneous substance as brick, but on this basis the crushing strength as measured by the German method would be about one-half that found by the American method, while the ratio of the strengths measured when testing a half brick, either flat or on edge, would be about one to one-third. While these ratios can not be expected to hold closely, yet they emphasize the necessity for noting the shape and size of the test specimens when comparing the results obtained by different methods.

The German specifications for sand-lime brick call for a crushing strength of 140 kg per square centimeter (about 2000 pounds per square inch).[43] The building code issued by New York City in 1905 specifies that the average crushing strength for five bricks shall be not less than 3000 pounds per square inch, no brick falling below 2500. The American Society for Testing Materials has endeavored to classify bricks according to their crushing strength, and follows.[41]

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[39] Burchartz, Lufthalk and Luftkalkmortel, Mitt. d. Kgl. Materialprufungsamt, p. 113; 1908.
[40] Report of Committee C-3, A. S. T. M.; 1913.
[41] Report of Committee C-3, A. S. T. M.; 1915.
[42] Burchartz, loc. cit.
[43] Schleier, Specifications for Sand-Lime Brick, Tonind. Zeit., 37, p. 1234.

Average crushing strength per square inch (5 samples):

| | |
|---|---|
| Class A | 5000 pounds and over |
| Class B | 3500 to 5000 pounds |
| Class C | 2000 to 3500 pounds |
| Class D | 1500 to 2000 pounds |

It will be noted that, if the ratio mentioned is assumed correct the German specifications call for a Class B brick,

(*b*) *Transverse Strength.*—The transverse strength of a brick is measured by supporting the brick at both ends and applying a load in the middle until rupture occurs. It indicates the resistance which the brick is able to offer to any force trying to bend it.

The modern method of measuring the transverse strength has been pretty generally adopted, so that there is less difficulty in comparing the results of different investigators. It consists, briefly, of mounting the brick on two parallel supports 7 inches apart. The load is applied by means of a blunt knife-edge, which is pressed down on the brick midway between and parallel to the supports. The brick is tested flat.

Evidently the load required to break the brick will depend upon the breadth and depth as well as the distance between the supports. The breaking load is therefore seldom reported, because to do so would require a detailed description of the test. A factor which includes all of these variables is the modulus of rupture. This is equal to 1.5 times the breaking load multiplied by the distance between the supports and divided by the width of the brick times the square of its thickness. Expressed numerically:

$$M = \frac{3}{2}\frac{wl}{bd^2}, \text{ where}$$

$m$ = Modulus of ruptures in pounds per square inch
$w$ = Breaking load in pounds
$l$ = Distance between supports in inches
$b$ = Breadth of brick in inches
$d$ = Depth of brick in inches

When a brick is loaded transversely in the manner indicated, the upper fibers are subjected to compression and the lower fibers to tension. Failure will be due, therefore, to tension or compression, whichever is the weaker, and the modulus of rupture is supposed to approximate the value of the weaker strength in pounds per square inch. However, it does not, either theoretically or practically, agree with the compressive or tensile strength, but is intermediate between them.[44]

[44] Merriman, Mechanics of Materials, p. 131.

The New York City building code, issued in 1905, specified that the average modulus of rupture for five bricks should be not less than 450 pounds per square inch, no brick falling below 350. Committee C–3 of the American Society for Testing Materials realizes that the modulus of rupture offers a most valuable criterion for the differentiation of bricks, but does not feel that sufficient data are at hand to warrant placing definite values in the specifications. The results of the tests included in the 1915 report show the following average values:

| Modulus of rupture in pounds per square inch: | |
|---|---|
| Class A | 1482 |
| Class B | 668 |
| Class C | 621 |
| Class D | 469 |

(*c*) *Absorption.*—All bricks are more or less porous. When a brick is exposed to the weather, some of its pores become filled with water. This water may freeze and set up internal strains, water may be conducted through the brick by capillary action, or it may leach out the soluble salts and deposit them on the surface as efflorescence. Some of the pores are more or less inclosed in the interior of the brick and can take up water only with difficulty or not at all. It is, therefore, advisable to measure the absorptive power of the brick rather than its true porosity.

To make this test, the dry bricks are weighed, placed in water, and again weighed at the end of a given time. The increase in weight represents the amount of water absorbed. In spite of the simplicity of the operation, many methods have been devised for measuring absorption. Thus, the brick may be partially or totally immersed or even boiled in water under reduced pressure. The time of immersion may be anywhere from one-half hour to 48 hours Some investigators claim that the rate of absorption is more important than the total amount of water taken up, because under ordinary conditions of exposure no brick has an opportunity to become saturated. The rate can be determined by measuring the absorption at a number of different periods.

The New York City building code recommends that the bricks be placed in water sufficient to cover all but the top half inch, and that they be weighed at the end of one-half hour, 4 hours, and 48 hours. The average absorption for five specimens shall not be more than 15 per cent at the end of 48 hours, no one being more than 20 per cent.

Committee C–3 of the American Society for Testing Materials recommends that the bricks be completely submerged in boiling water for four hours. In 1913 the absorption was used together with the crushing strength as a basis for classifying bricks, as follows:

| | |
|---|---|
| Maximum allowable absorption: | |
| Class A | 5 per cent. |
| Class B | 12 per cent. |
| Class C | 18 per cent. |
| Class D | No limit. |

The results of tests reported in 1915 throw some doubt on the advisability of this classification, so that the absorption has been eliminated from the specifications until such time as further data are available.

(*d*) *Freezing*.—The resistance of a brick to the action of frost is believed to be one of the most important properties. It is extremely unfortunate that the excessive cost of the test has prohibited its general adoption, so that the results which thus far have been obtained are not sufficient to use as a basis for specifications. It is doubtful whether a freezing test would be specified in any event, the excessive cost being regarded as an undue burden to the trade.

The method generally used is to saturate the brick with water and freeze it, thaw it out by immersion in warm water, and freeze it again; repeat the operation a number of times, generally 20. The crushing strength of a brick before and after freezing may be compared, its loss of weight noted, or the observer may merely report remarks as to whether the brick disintegrated, cracked, etc.

The Brard sodium-sulphate method has been considered favorably as a substitute for the freezing test. This depends on the fact that when sodium sulphate crystallizes out of a saturated solution expansion takes place. By soaking the brick in the solution and then drying it this expansion occurs in the pores and has an effect similar to the formation of ice. It is much less laborious and more rapid than the freezing test and does not require such costly equipment.

(*e*) *Fire test*.—The fire test as usually conducted is designed to indicate the amount of salvage which might be expected from a brick wall which has been exposed to a fire.

The bricks are built into a panel which forms the door of a furnace or they are laid in the wall of a small building. A fire is started inside of the furnace or building and the temperature raised to 1700° F in one hour. A stream of water is then played on the bricks through a fire hose. If the bricks are in sufficiently good condition, some of them may be taken out and tested for crushing strength, etc. Generally, however, the results of the test are reported simply as remarks on the appearance of the bricks.[45]

The test is sometimes conducted by merely laying a few bricks loosely on the floor of a furnace, heating them, and quenching them as before.[46]

The behavior of sand-lime brick when exposed to fire has recently been thoroughly investigated by Ernest.[47] His results may be abstracted briefly as follows: Two brands of sand-lime brick were heated gradually in a kiln. Eleven of each kind were withdrawn at intervals and tested with the following results:

| Temperature, ° C | Modulus of rupture | | Crushing strength | |
|---|---|---|---|---|
| | First brand | Second brand | First brand | Second brand |
| Start | 430 | 717 | 4328 | 3430 |
| 300 | 238 | 418 | 4980 | 3900 |
| 400 | 145 | 388 | 4650 | 3710 |
| 500 | 95 | 197 | 3720 | 3340 |
| 600 | 83 | 142 | 4440 | 3320 |
| 700 | 68 | 100 | 4155 | 2640 |
| 800 | 68 | 116 | 3130 | 2400 |
| 900 | 33 | 85 | 2050 | 1700 |
| 1000 | 33 | 61 | 2440 | 1680 |
| 1100 | 26 | 37 | 2350 | 1280 |
| 1200 | 47 | 101 | 1310 | 1670 |
| 1250 | 74 | ........ | 2750 | ........ |
| 1370 | 554 | 157 | 3341 | 4860 |

The increase of strength up to 300° C is probably due to the drying out of the material. Further heating may result in the dehydration of the calcium silicate, thus weakening the bond. At the highest temperature a new silicate has probably been formed, so that the material has been transformed into a substance similar to silica brick.

There were no signs of warping or shrinking, the bricks retaining constant volume throughout the test. Several of them cracked, however. This was observed to be due to the presence of lime spots, the injurious effects of which have been previously noted.

Other investigators when conducting fire tests in the usual manner have obtained results differing quite widely from those quoted above.

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[45] Humphrey, Fire-Resistive Properties of Various Building Materials, U. S. Geol. Sur., Bull. 370; 1909.

[46] Perrine, Tests of Fireproof Construction for the City of New York, School of Mines Quarterly; April, 1913.

[47] Trans. American Ceramic Soc., p. 83; 1910.

(*f*) *Miscellaneous.*—In addition to the above, other tests are sometimes called for, such as the resistance of the brick to the action of sea water, the rate of absorption of carbon dioxide by the lime mortar in which the bricks are laid,[48] and the adhesion of the mortar to the brick.[49]

## 2. SUMMARY

Sand-lime brick is such a comparatively new material that not many tests of the American product have been published. The industry is older in Germany, and there the different brands have been thoroughly investigated.[50]

The following table contains a number of tests of the American product which have been collected from the literature and gives an idea as to what can be expected from sand-lime brick. Small discrepancies due to different methods of testing have not been noted, but can be ascertained by reference to the original papers.

[48] Michaelis, Tonind. Zeit., 34, p. 600.

[9] Douty and Gibson, Proc. A. S. T. M.; 1908.

[0] Burchartz, Prufung und Eigenschaften der Kalksandsteine, Mitt. d. Kgl. Materialprufungsamt; 1908.

## TABLE 2.

### Properties of Sand-Lime Brick

| Authority * | State in which bricks made | Dry bricks | | | | Wet bricks—Loss due to wetting in— | | Loss due to freezing in— | | | | Loss due to fire in— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Crushing strength | | Trans-verse strength, modulus of rup-ture | Absorp-tion | Crush-ing strength | Trans-verse strength | Crush-ing strength | Trans-verse strength | Absorp-tion | Weight | Crushing strength | | Trans-verse strength | Absorp-tion |
| | | Ameri-can method | German method | | | | | | | | | Dry | Wet | | |
| | | lbs. / in.² | lbs. / in.² | lbs. / in.² | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent |
| A | | 2684 | | 320 | 8.6 | 27.5 | 31.3 | 35.6 | | | 1.06 | 32.7 | | 94.6 | |
| A | | 2772 | | 505 | 14.9 | 31.8 | 51.4 | 34.3 | | | .17 | a 1.5 | | 88.8 | |
| A | | 3240 | | 406 | 14.8 | 27.7 | 11.9 | 21.5 | | | a .78 | 20.6 | | 95.2 | |
| A | | 2476 | | 334 | 14.6 | 27.7 | 21.2 | 54.8 | | | .03 | 16.5 | | 90.5 | |
| A | | 1870 | | 197 | 15.4 | 38.5 | a 25.3 | 30.3 | | | a .56 | 41.8 | | 87.9 | |
| A | | 3273 | | 370 | 14.3 | 40.0 | 19.6 | 45.7 | | | .29 | 37.4 | | 92.8 | |
| A | | 3190 | | 494 | 9.1 | 35.6 | .9 | 47.7 | | | .15 | a 53.1 | | 92.5 | |
| B | | 4988 | | 729 | | 30.7 | 39.3 | 39.0 | 36.3 | | | 12.5 | | 90.2 | |
| B | | 3039 | | 471 | | 43.3 | 75.1 | 47.0 | 43.1 | | | 42.5 | | 86.7 | |
| B | | 3785 | | 435 | | 38.5 | 10.6 | 51.7 | 21.9 | | | 17.0 | | 71.7 | |
| B | | 5102 | | 626 | | 40.9 | 32.9 | 49.8 | 40.6 | | | 24.3 | | 92.0 | |
| B | | 5802 | | 810 | | 55.0 | 51.0 | 52.3 | 45.7 | | | 25.1 | | 93.7 | |
| C | New York | 5015 | | | | | | | | | | | | | |
| C | | 3380 | | 264 | 14.0 | 17.1 | | | | | | | | | |
| C | | 1950 | | 342 | 13.5 | a 17.4 | | | | | | | | | |

a Gain instead of loss.

* A=Woolson, Report of Tests Upon Sand-Lime Brick, Proc. Sand Lime Brick Assn., p. 211, 1905; B=Underwriters' Laboratories, quoted by Lazell, Proc. Sand Lime Brick Assn., p. 42, 1908; C=Watertown Arsenal, Report of the Tests of Metals and Other Materials, p. 274, 1907; D=University of Minnesota, Proc. Sand Lime Brick Assn., p. 16, 1909; E=Peppel, Manufacture of Sand-Lime Brick, Ohio State Geological Survey Bull. No. 5, p. 56, 1905; F=Purdy, Sand-Lime Brick Tests, Rock products, 10, p. 43; G=Humphrey, Fire-Resisting Qualities of Building Materials, U. S. Geol. Survey Bull. 370, p. 77, 1909; H=Emley, Properties of Sand-Lime Brick, Proc. Sand Lime Brick Assn., p. 44, 1912; I=Bureau of Standards, Results not previously published; J=American Society for Testing Materials, Report of Com. C-3, 1915.

TABLE 2—Continued

| Authority | State in which bricks made | Dry bricks | | | | Wet bricks—Loss due to wetting in— | | Loss due to freezing in— | | | | Loss due to fire in— | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Crushing strength | | Transverse strength, modulus of rupture | Absorption | Crushing strength | Transverse strength | Crushing strength | Transverse strength | Absorption | Weight | Crushing strength | | Transverse strength | Absorption |
| | | American method | German method | | | | | | | | | Dry | Wet | | |
| | | lbs./in.² | lbs./in.² | lbs./in.² | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent | Per cent |
| C | | 2030 | | 300 | 15.5 | a 4.9 | | | | | | | | | |
| C | | 3070 | | 662 | 11.8 | a 6.8 | | | | | | | | | |
| C | | | | | 15.1 | | | | | | | | | | |
| D | Minnesota | 3153 | | 344 | 15.9 | | | | | | .40 | (b) | | | |
| E | Pennsylvania | 3846 | | | 10.5 | | | a 21.4 | | a 3.8 | | | | | |
| F | Ohio | 2230 | | | 10.8 | | | a 37.7 | | | | | | | |
| G | | 2035 | | 319 | 15.8 | 27.4 | | | | | | 14.0 | 41.7 | 82.5 | a 4.2 |
| H | Pennsylvania | 4990 | 2635 | 793 | 13.9 | 15.0 | | | | | | (c) | | | |
| H | Ohio | 3210 | | 566 | 10.1 | 9.0 | | | | | | (c) | | | |
| H | Colorado | 3060 | 2270 | 551 | 11.8 | 7.0 | | | | | | (d) | | | |
| H | New Jersey | 2660 | 982 | 386 | 13.2 | 19.0 | | | | | | (c) | | | |
| H | Georgia | 3380 | 1110 | 442 | 14.7 | 30.0 | | | | | | (c) | | | |
| H | Texas | 2900 | 940 | 356 | 13.3 | 29.0 | | | | | | (c) | | | |
| H | Minnesota | 4180 | 2235 | 674 | 15.2 | 13.0 | | | | | | (c) | | | |
| H | Kentucky | 3560 | 2460 | 569 | 13.5 | 18.0 | | | | | | (c) | | | |
| H | Georgia | 3400 | 1995 | 517 | 13.7 | 21.0 | | | | | | (c) | | | |
| H | Wisconsin | 3920 | 1350 | 568 | 14.2 | 34.0 | | | | | | (c) | | | |
| H | New York | 4590 | 1705 | 563 | 11.0 | 41.0 | | | | | | (c) | | | |
| H | Michigan | 2940 | 1360 | 381 | 11.6 | 20.0 | | | | | | (c) | | | |
| H | Minnesota | 3130 | | 554 | 14.8 | 35.0 | | | | | | (c) | | | |
| H | Michigan | 4070 | 2010 | 602 | 12.5 | 28.0 | | | | | | (c) | | | |
| H | do | 1740 | 1110 | 285 | 13.7 | 16.0 | | | | | | | | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H | New York | 3720 | | 685 | 11.7 | 21.0 | | | | | | | | | |
| H | Nebraska | 3350 | 1835 | 418 | 13.8 | 15.0 | | | | | | (c) | | | |
| H | California | 2800 | 2560 | 457 | 13.0 | 34.0 | | | | | | (c) | | | |
| H | Florida | 3190 | 1190 | 558 | 16.9 | 20.0 | | | | | | (c) | | | |
| I | do | 8060 | | 1184 | 9.1 | | | | | | | | | | |
| I | do | 10 050 | | 1128 | 8.0 | | | | | | | | | | |
| I | Wisconsin | 2219 | | 438 | 19.6 | 15.9 | | | | | | | | | |
| I | New York | 2566 | | 448 | 12.9 | 10.4 | | | | | | | | | |
| I | Indiana | 2174 | | 338 | 18.8 | 18.9 | | | | | | | | | |
| I | Minnesota | 2190 | | 476 | 11.2 | 20.8 | | | | | | | | | |
| I | Pennsylvania | 3576 | | | | | | | | | | | | | |
| I | Indiana | 2006 | | | | | | | | | | | | | |
| I | Michigan | 2050 | | | | | | | | | | | | | |
| J | Pennsylvania | 4542 | | 438 | 13.9 | | | | | | | | | | |
| J | do | 4334 | | 592 | 12.3 | | | | | | | | | | |
| J | Indiana | 2795 | | 347 | 21.8 | | | | | | | | | | |
| Average | | 3470 | 1775 | 505 | 13.5 | 23.6 | 25.8 | 32.2 | 37.5 | [a] 3.8 | 0.09 | 17.7 | 41.7 | 89.2 | [a] 4.2 |

[a] Gain instead of loss. [b] Cracked. [c] Sound. [d] Disintegrated.

WASHINGTON, March 28, 1916.

# APPENDIX

## 1. DESCRIPTION OF PLANTS

In order to give a better idea of the actual process of manufacture of sand-lime brick, it is thought advisable to include brief descriptions of a few typical plants. It must be remembered that each factory differs from every other in some particular. This is made necessary by variations in local conditions. The descriptions appended hereto can not be considered as models to be followed in designing a new factory, but the designer should select such essential features from each as are required by the conditions he has to meet.

(*a*) The plant located at Spokane, Wash., is on the Great Northern Railroad about 10 miles north of Spokane, Wash. The sand bank is in the form of a small hill. This has been opened by starting at the ground level on the side of the hill nearest the factory, and making a cut about 30 feet wide straight back toward the summit of the hill. At present this cut has been extended back about 100 feet, making a working face about 60 feet high. The sand is quite clean, containing very little dirt or iron pyrites. The grains are nearly uniform in size; there is no coarse material and very little fine. The sand is shoveled into tramcars and hauled by cable up an incline to the factory. Five cars out of every six are dumped into a large storage bin. The sixth car is stopped about halfway up the incline, and its contents discharged into a chute which leads to a steam-heated rotary drier. The high-calcium quicklime made at Evans, Wash., is bought in lump form and is crushed to the size of a pea in a small Gates gyratory crusher. The lime is fed into a tube mill, where an equal weight of dried sand is added, and the whole thoroughly mixed and ground to a fine powder. The mixture then goes to a pug mill on a belt conveyor, the speed of which accurately regulates the proportion of sand put in. Sufficient water to hydrate the lime is also added in this pug mill. The mass is then stored in a silo for 24 hours to permit the hydration to take place. It is then put through a one-half inch rotary screen to take out roots, sticks, etc., and is made up to the required consistency by adding water in another pug mill. It is then pressed into shape in a four-mold vertical press, which has a capacity of about 20 000 bricks per day. The green bricks are picked by hand from the press table and piled on small cars, which are put in the hardening cylinder. The cylinder is filled during the day and the bricks are cured all night. The maximum steam pressure is about 140 pounds, and this is maintained for about seven hours.

(*b*) Another plant is located about 10 miles north of Minneapolis, near New Brighton, and is on a belt-line railroad which is operated by the Northern Pacific; Great Northern; Chicago, Milwaukee & St. Paul; and Minneapolis, St. Paul & Sault Ste. Marie railroads. The sand lies on the surface of the ground in a bed from 10 to 20 feet thick. It is covered with a very thin layer of soil and contains a few thin beds of sandy loam, but is otherwise quite clean. The texture is fairly uniform, with no gravel. The sand is shoveled into tramcars, run to the foot of an incline by gravity, and pulled up into the factory by cable. Here it is dumped into a small bin, which discharges near the boot of a bucket elevator. The lump lime required is brought from Manistique, Mich. Two wheelbarrows of lime are put in a quencher and covered with water. After the first violent slaking has ceased the quenchers are put into a hardening cylinder, where they fit under the cars of brick. The hydration is thus completed by high-pressure steam at the same time that the brick are cured. After steaming the hydrate is put through a coarse screen to remove any core and break up the lumps and then through an air separator. The extremely fine hydrate is blown by this air separator into a storage bin. One shovelful of hydrate and four shovelfuls of sand are mixed roughly by turning over a few times and put into the bucket elevator. This discharges to a coarse screen, where sticks, gravel, etc., are removed. The mass then falls into a double-screw mixer, where enough water is added to give it the proper consistency. The mixer conveys the material to the press. The plant is equipped with two two-mold rotary-table presses, which are being operated 13 hours a day to make 61 000 bricks. There are five hardening cylinders, which are put into operation whenever they are filled, at any hour of the day or night. Generally, three cylinders are in operation, one is being filled and one emptied. The bricks are cured with steam at 120 pounds pressure for 11 hours.

(*c*) The plant which supplies Milwaukee is located near West Bend, Wis., about 40 miles northwest of Milwaukee on the Chicago & North Western Railway. The sand covers the surface of the ground to a depth of about 20 feet. It is uniform in texture, containing a little gravel and a few seams of sandy loam. The topography permitted erecting the plant in such a way that the roof is about on a level with the sand deposit, and the sand is brought in by a drag. This is an iron scoop, which holds about a yard and is carried by a steel cable in such a way that it drags along the ground. The cable is operated by a hoisting engine on the roof of the factory and passes through a sheave mounted on a pole at the farther side of the sand bank. As the scoop is drawn toward the factory it digs into the ground and picks up its load of sand; returning, it slides back over the surface of the ground empty. To get sand from a different part of the bank it is merely necessary to take the sheave off one pole and put it on another. The sand bank is on top of a hill, and a small runway connects it with the roof of the factory, so that the scoop delivers the sand directly to a coarse rotary screen. The gravel which is removed by this screen, together with brickbats and similar material, is put through a small jaw crusher and utilized as sand. The sand passing the screen falls directly to the floor of the factory, ready for use. The quicklime is burned at Marblehead, Ill. It is slaked in an especially designed hydrator, for a detailed description of which see page 19. From this machine the hydrate is taken by a screw conveyor and put through an air separator. This blows the fine material into any one of four bins, which are arranged in a row, with a belt conveyor running under them. By means of this conveyor hydrate can be taken from any bin and delivered to the floor of the factory near the sand pile. One shovelful of hydrate and four shovelfuls of sand are put in a concrete mixer and mixed for one minute. The material is then dumped into a bucket elevator, which takes it to a storage bin. This bin is arranged to feed any one of four belt conveyors, each of which delivers to a double-screw mixer, where the water is added, and finally to a press. Three of the presses are of the rotary-table type, the other one being vertical. There are five hardening cylinders, which are put in operation as soon as they are filled. They are connected to each other by a series of by-pass valves in such a way that the waste steam blown out of the cylinder about to be opened can be used in heating up a cylinder of green brick. The cylinder heads are provided with hinges. The maximum steam pressure is 150 pounds, and this is maintained for seven hours. The factory has a capacity of 91 000 brick per day.

(*d*) There is a factory in the suburbs of Grand Rapids, Mich., about 5 miles from the center of the city. The Pere Marquette Railroad offers shipping facilities, but most of the output is hauled to market by horse. The sand is rather fine and contains but little clay or gravel. It occurs in small hills or dunes, which have a maximum height of about 20 feet above drainage. It is hauled to the factory, a distance of about 100 yards, by horse and cart, each cart holding 2 yards, and is dumped into a bucket elevator, which takes it to the roof of the factory and dumps it in a pile on the floor. This pile is generally sufficient to last about a week, so as to give the sand an opportunity to dry out if necessary. The lime is brought from Indian River, Mich. Two hundred pounds of lime are put in a quencher and 100 pounds of water added. As soon as violent action has ceased, the quencher is put in a hardening cylinder under the brick cars, where the lime is subjected to the action of high-pressure steam while the bricks are being cured. The hydrate resulting from this treatment is raked through a coarse screen to remove the core and break up the lumps and is then further pulverized by a hammer mill. It is then stored in a bin whose outlet is near the sand pile. Four shovelfuls of sand are mixed with one shovelful of lime by turning them over a few times. The mixture is delivered by a bucket elevator, through a coarse screen, which removes the gravel, into a double-screw mixer. The necessary amount of water is added here, and the material is then ready for the press. The factory is equipped with one two-mold, rotary-table press and three hardening cylinders. The cylinders are operated in rotation in such a way that two are in use, while the other is being emptied and filled. The maximum steam pressure used is 120 pounds, which is maintained for seven hours. The output is 26 000 bricks per day.

(*e*) Another factory is located in the suburbs of Kalamazoo, Mich., on the Michigan Central and the Grand Rapids & Indiana railroads. Almost all of the output is sold locally and is hauled to market by horse. A deposit of fairly clean sand, containing some gravel, and which is about 20 feet deep, is found about 7 miles from the factory. The sand is shipped to the factory by freight over the Michigan Central Railroad at the rate of two cars a day. It is shoveled from the cars to a bucket elevator, which takes it to a coarse screen for removing the gravel. The sand passing the screen falls on a belt conveyor, which takes it into the factory and dumps it on the floor. The lime is brought from Indian River, Mich. Two hundred pounds of lime are put in a quencher and 100 pounds of water added. As soon as violent action has stopped the mass is dumped into a silo. There are two silos, each having sufficient capacity to supply the factory for four days. One barrow of sand, two shovelfuls of brickbats (if available), and a small barrow of hydrate are put in a wet pan and mixed for one and one-half minutes. Two barrows of sand are then added and mixed for another minute. The required amount of water is run in during this minute. The mixture is then scooped out of the wet pan and dumped into a bucket elevator, which delivers it to a storage bin. From the bin it is fed by a rotating horizontal plate into a two-mold, rotary-table press. The factory is equipped with one press and three hardening cylinders. One cylinder is operated during the day and two at night. The maximum steam pressure in the cylinder is 120 pounds, which is maintained for 10 hours. The output of the plant is 26 000 bricks per day.

(*f*) There is a factory located about 3½ miles from Dayton, Ohio, on the Cleveland, Cincinnati, Chicago & St. Louis Railway. In spite of the close proximity to the market it is found economical to make all deliveries by freight. The sand bank forms a good-sized hill, which has been cut back so that the working face is now about 60 feet high. The sand is rather coarse and contains a good deal of gravel, but little clay. It is shoveled into small tramcars, which are run by gravity to the foot of a belt conveyor. This takes the sand into the factory and dumps it on a coarse screen, where the gravel is removed. The sand passing the screen falls in a pile on the floor of the factory ready for use. The lime is purchased from the manufacturer at Delaware, Ohio. In order to hydrate it, 700 pounds of water are put in a large quencher and 800 pounds of lime added. As soon as the violent action has ceased the hydrate is dumped into a silo. There are two silos, each large enough to hold a week's supply of hydrate. One barrow of sand and one of lime are put in a wet pan and mixed for two minutes. Then two barrows of sand are added and mixed for one minute. The required amount of water is added during the last minute of mixing. The contents of the pan are removed by a scoop and delivered to a storage hopper by means of a bucket elevator. From here the material is fed as needed to a two-mold, rotary-table press. The factory is equipped with one press and two hardening cylinders. One cylinder is operated during the day and the other at night. For curing the brick a steam pressure of 120 pounds is maintained for 10 hours. The daily output of the factory is 20 000 bricks.

(*g*) Another sand-lime brick plant is located near Hummelstown, on the Philadelphia & Reading Railway, about 10 miles east of Harrisburg, in Dauphin County, Pa. The same company operates a quarry for the production of cut sandstone for building purposes. In any such quarry there is always a great amount of waste material. Natural fissures and seams break up the beds of stone in such a way that only a limited amount of it can be cut out in the form of building blocks of given dimensions and without flaws. The smaller pieces of stone which remain are crushed to sand, and from this sand-lime brick is made. The sand contains about 94 per cent silica, enough iron to give it a decided reddish-brown color, and practically no clay or organic matter. The grains differ in form from river or sea sand, because they have not been eroded and therefore are angular rather than spherical.

Stone is brought from the quarry in small side-dump cars, holding about 2 tons each. If wet, it is discharged into a No. 5 gyratory crusher, which reduces it to pieces about 2 inches and smaller. It then passes through a direct-fired rotary drier and is discharged into a dry pan, which completes the reduction to sand. If the stone is dry when received, it is put through another No. 5 crusher and discharged directly to the dry pan. The sand from the dry pan is elevated to a small rotary screen, two sections of which are four-mesh and two five-mesh. The material passing through the screen is conveyed to the sand bin ready for use. The tailings are put through a No. 3 gyratory crusher and returned to the screen. A very pure high-calcium quicklime is obtained from Thomasville, Pa. This is reduced to about one-fourth inch and smaller by a corn crusher. The lime is mixed with part of the sand by grinding the materials together in a 22-foot tube mill. The proportions are accurately controlled by means of a 36-inch continuous measuring machine, which delivers the ingredients to the tube mill in the ratio of 5½ parts of lime to 22½ parts of sand. The material coming from the tube mill passes through a small pug conveyor, where sufficient water is added to hydrate the lime, and is then delivered to one of three silos. These bins are of such a capacity that the material remains in them for 24 to 36 hours, in order that the lime may have sufficient time to become completely hydrated. The material coming from the silo passes through a 48-inch measuring machine, where the rest of the sand is added. The proportions delivered by this machine are 22 parts of material from the silo to 58 parts of sand. The final mix therefore contains 6.71 per cent of hydrated lime, which is equivalent to 5.08 per cent of quicklime. The mixture passes through a small disintegrator, which breaks up any lumps that may be formed of the damp material in the silo. It is then conveyed to small storage bins over the presses. It is taken from these bins as required and delivered to the presses by pug conveyors. The water required for making the material of proper consistency for pressing is added in these conveyors. There are four presses of the four-mold vertical type. Their combined capacity is about 80 000 bricks per day of 10 hours. After being pressed the bricks are cured with steam, for which purpose three hardening cylinders are used. These are of the usual type, except that they can be opened at both ends to facilitate filling and emptying them. Each cylinder is capable of holding 22 trucks (22 000 bricks). They are all filled during the day and operated for 11 hours at night, with a steam pressure of 130 to 140 pounds. After curing the bricks are permitted to cool on the trucks for 24 hours and are then conveyed by a gravity carrier to the freight car for shipment.