Burning Brick

—IN—

Down-Draft Kilns.

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W. D. RICHARDSON.

T. A. RANDALL & CO., PUBLISHERS,
Indianapolis, Ind.

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Prepared as a Manual for the
Author's "Kiln Records."

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PREFACE.

This little book is published as a manual for "Kiln Records," the two books comprising a system of brick burning that was prepared for one of my clients, a company having three brick plants. The kilns at these plants were all of the down-draft type, some round and some rectangular. It was desired to establish a uniform system of burning at these plants that would give better results—a larger percentage of first grade brick, less fuel, less time. The burning was done in a haphazard manner, the modus operandi depending eneirely upon the empirical judgment of the burner, without any well-defined system and with absolutely no means of observing or recording the progress of the fires, the temperature or chemical changes taking place in the kiln, excepting that full-sized trial brick were pulled out through the casing from time to time, with the consequent inrush of cold aid. There were no peep-holes provided for looking into the kilns, no measurement of draft, temperature or settle, and no cones used to determine the finishing point.

I made some changes in the kilns and furnaces, but my efforts were directed chiefly toward establishing at all the plants a uniform method of proceedure from start to finish of the burning operation and especially to provide means for systematically observing and recording, at regular intervals, the progress of the burning. Fomulating this method and the putting of my instructions in practical shape for the use of brick burners proved to be a task of such magnitude that I decided to give the matter a little wider scope and bring it out in a more permanent form for all similar cases in my practice and make it accessible to any who might think it worth the small investment in books and apparatus.

Most of the matter in this book was first published in a series of articles in THE CLAY-WORKER, and is here collected into more convenient form for reference.

It is believed that the result of applying the system herein laid down will be of great assistance to brick manufacturers in bringing under better control the important operation of burning. Any criticism or practical suggestions for improvement will be gratefully acknowledged.

WILLARD D. RICHARDSON.

Columbus, Ohio.

BURNING BRICK IN DOWN-DRAFT KILNS.

CHAPTER I.

Essentials of Good Burning.

BURNING BRICK in down-draft, periodical kilns involves the same principles of combustion of fuel and the same chemical and physical laws acting upon the clay under fire, as the burning of brick in any other form of kiln, but the practical management of down-draft kilns to produce the best results requires some special knowledge and a special method of procedure that is, in a measure, peculiar to this type of kiln. As it is our purpose in this book to show the importance of careful and regular observations of the action of the fires upon the brick throughout the whole time of burning, and also of making a systematic record of such observations, where the down-draft kiln is used, no consideration is given to the general principles of burning, other than directly pertains to this end. For this reason, also, no mention is herein made of other forms of brick kilns. Moreover, as this treatise is designed for the use of practical men in brickyards, only such matter will be presented, such apparatus described, as can be easily understood and used by the average brickburner without technical education.

It is the desire and should be the active purpose of every brick manufacturer to so conduct the whole operation of burning as to secure good, uniform, positive results from every kiln. To accomplish this requires:

1. A good kiln, adapted to the clay and product, to the fuel used and to all other local conditions.

2. The unceasing care and vigilance of an intelligent, temperate, reliable man, who takes an interest in his work and is always seeking to learn and striving to improve results.

3. Skillful and systematic management.

The first requirement, a good kiln, does not come within the scope of this treatise. A good kiln will not of itself insure good burns, but it is true that the better the kiln, other things being equal, the better the results of the burning. Thus, a good kiln does not make the other two requirements so vitally essential, since, as a rule, the better the kiln the less skill required to operate it. Probably no kiln requires so much care and skill to get good results as the simplest form of open-top, scoved kiln. By a good kiln is meant one that is not only designed and constructed upon scientific principles, but one that is especially adapted, in all its features, to the conditions in any special case. Such a kiln is the product of the educated and experienced brickworks engineer, superintendent or manufacturer, and may be neither patented nor advertised.

The second requirement, a thoroughly competent man, is a rarer and more uncertain factor than the proper kiln. With such a man even an inferior kiln may turn out good results. Where the owner or manager himself understands the practical requirements of brick burning and has this important operation well systematized, in the manner we shall show, he will be able from among his employes or acquaintances to select a man to take charge of this work, follow instructions and the records of previous burns, and soon become a more efficient burner than one that could be obtained elsewhere. Such a man should be encouraged by good wages and every facility for carrying on the work. In getting a burner from outside, however, no judgment of his efficiency can be formed from the amount of wages he demands nor, oftentimes, from the testimonials he presents.

In this book, the first two requirements are assumed, and attention given exclusively to promoting the third essential of successful brick burning by laying down a systematic method of procedure and providing for the keeping of an accurate record of the conditions and progress of every kiln and every burn. Such a method of conducting the burning of the kilns and of recording and preserving data can not but lead to improvement, both in quality of brick and economy of fuel, and to such a mastery of this most complex and vital operation of brick manufacture that positive, definite results can always be assured.

CHAPTER II.

Preliminaries.

KILN REPAIRS.

The first thing that should receive the attention of the brickburner is the condition of the kiln after the burning and emptying. The kiln should be carefully looked over before the emptying is finished, so that any necessary work upon it can be done without delaying manufacturing operations.

All kilns need cleaning regularly and will get out of repair more or less by reason of the severe strain of repeated heating and cooling. Flues in the bottom will become filled with sand and brick chippings, and flues in the walls be partially closed by the expansion of the lining, or the stress of the crown arch. Flue walls will settle and get out of shape, causing an uneven floor. Floor brick will break and have to be replaced. Flash walls will crack and warp and pull away from the kiln wall or draw in toward it, and the space for combustion gases become constricted, causing further damage. The furnace throat arches will pull down and the kiln lining inside of flash walls come in, especially if there have been poor materials or poor workmanship. The crown arch will get out of shape or fall in entirely. In the former case it should be raised up either in part or in whole and a portion taken out and relaid. If this is neglected until the latter occurs, then the whole must be relaid in the best manner. Cracks will appear in the walls and crown, or in the flues, admitting cold air to the kiln and interfering with the draft. The crown may leak and cause damage to the brick during the setting or water-smoking. The furnaces will need to be thoroughly cleaned after every burn and repairs frequently made to arches, doors, charging or coking tables, or grate bars. The stack or chimneys may crack and need daubing. Underground smoke flues outside of kiln may become damaged. Drains may become clogged and the bottom of kiln flues or stack become water-soaked. All or any of these damages to kiln may occur and injure its efficiency.

The proper man to look after kiln repairs is the burner, since he must be responsible for the results of the work of the kiln. He should have no occasion to excuse bad results on account of remediable defects in the kiln. It is not only true in kiln management that "a stitch in time saves nine," but that it also saves fuel, time and labor and an excessive loss from defective brick.

Of course, there is a great difference in kilns as to getting out of repair. Many, in building kilns, do not count upon the cost of repairs and the annoying delay often caused thereby. They look merely to making the first cost of the kiln as low as possible. Moreover, for this reason they also neglect proper drainage and the insulation of the kiln bottom from ground moisture, and thus for every dollar saved in construction they lose many times the amount in fuel, labor and time of burning. It is the duty of the brickburner, however, to make the best of conditions not under his control, and to get the very best results he can with the facilities afforded. He can and should prevent matters from getting worse by keeping the kilns clean, tight and in good order. To accomplish this he will generally be furnished with the requisite materials and assistance, if he shows proper interest in his work and produces good results for his employers.

The brickburner should learn to become handy with the trowel and hammer, so that, on a small yard especially, he can do much of the kiln repairing himself. By carefully observing the results of his work in this line he will learn how to improve upon it and to make the repairs more durable.

The brickburner should be provided with the necessary tools for cleaning out furnaces and for removing the sand and chippings from flues. He should also have trowel, hammer, mason's level and plumb, and straight-edge for making kiln repairs. These tools, together with his other apparatus, should be kept in place in the burner's office or tool house, convenient to the center of his operations.

SETTING.

To burn a kiln of brick intelligently and obtain the best results, the burner should know just what kind of brick are in the kiln, their condition and manner of setting. Hence, the brickburner should carefully observe the setting of every kiln and make an entry of these facts in the place provided in the kiln record books. The result of the burning can often be improved by changing the setting. A competent brickburner should be able to direct such changes.

PEEP-HOLES.

Convenient peep-holes, as shown in Fig. 1, should be provided in every kiln for observing the progress of the heat. Where these are not seen, and are not frequently and regularly used, upon a brickyard, it is a sure indication that the burner does not understand his business or does not know what he is doing, but is, for the most part, blindly following his own haphazard ways.

In a rectangular kiln there should be two permanent peep-

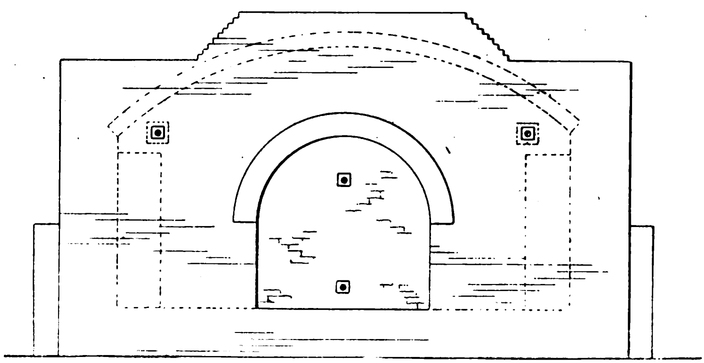


Fig. 1.

holes, flaring inside, in one end of the kiln, just in front of each row of flash walls and on a line with the spring of the crown. These peep-holes are used for observing the uniformity of the fires and for detecting any overfiring by noticing the first signs of fusion or pulling over of the brick. In a round kiln, of course, peep-holes cannot be placed so as to compare at a glance the uniformity of the fires, but there is a lower row of vent holes in the crown, through which, by raising the cover, it can be ascertained whether the brick are being overfired at any point. These vent holes are also sometimes used for admitting cold air for tempering the heat in the top of the kiln and forcing it to the bottom.

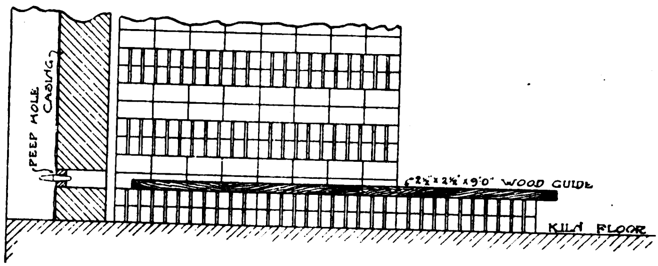


Fig. 2.

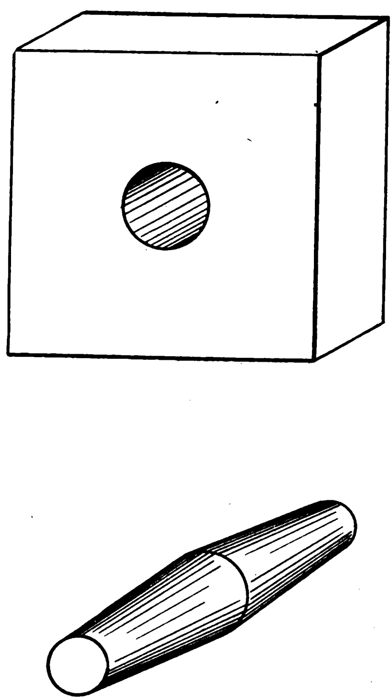


Fig. 3.

The peep-holes that are to receive attention in setting are the same in the round as in the rectangular kiln. They are placed in the casing of the doors in line with an unobstructed passage through the kiln from one door to the other. There should be two of these peep-holes, one near the top of the door, about midway from the top to the bottom of the kiln and the other formed in the third course of brick from the bottom. In order to insure that these holes will enable one to look way through the kiln, a wood strip must be used by the setters as a guide for keeping the open space on a straight line, in the manner shown in Fig. 2. When the door is cased up

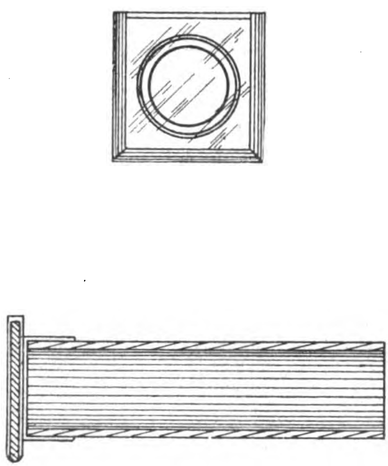


Fig. 4.

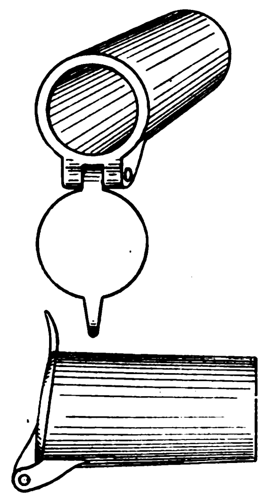


Fig. 5.

an opening is left in line with each hole, which is closed in the outer casing with a half brick, having a round hole in the center about one and one-quarter inches in diameter. Into the hole in this half brick is placed a clay plug about 7 inches long, tapered at both ends (Fig. 3). Both the half-brick and the plug are made out of green brick and burned moderately hard so as to be durable. In place of a plug a thin sheet of mica, or a piece of glass, can be used to cover the peep-hole, being stuck on with clay. Or, a piece of one and one-half inch iron pipe may be placed in the casing, projecting two or three inches, and a tin frame holding a piece of glass, can be made to fit tightly over the pipe as shown in Fig. 4. The special cast-iron peep-hole shown in Fig. 5 is sometimes used. This casting has an inside diameter of about one and one-quarter inches, and has a hinged cover, as shown.

These peep-holes are for observing the progress of the heat down the kiln and the variations of the heat from end to end of the kiln. They are also for watching the cones, which are placed where they can be easily seen from the peep-holes.

It is the duty of the brickburner to see that the peep-holes are properly provided in the setting and in the casing.

MEASURING TILE.

The burner should also see that the measuring tile are properly placed under each measuring hole. These are tile placed upon the top of the brick in kiln from which the measurements of settle are made. They are generally 2½x12x12 fireclay tile, hard burned, and should be placed at the same level in the kiln, and, if possible, upon the same height of brick in each kiln. Where the setting is low, piers can be built up for these tile.

CONES.

The pyrometric cones, one of the most valuable contributions to the clay industries in modern times, the work of the renowned German ceramist, Prof. Dr. H. Seger, are now so well known among the clayworkers the world over as to need no description. These have been made easily accessible to American clayworkers, at the low price of one dollar a hundred, by Prof. Edward Orton, Jr., Columbus, Ohio. To meet the increasing demand for the cones Prof. Orton has erected and equipped a building especially for their manufacture.

No brick manufacturer, using down-draft kilns, can afford to neglect the advantage given by these cones of controlling the burning of his brick to the extent of having the heat always brought to the proper point for finishing to secure the best results. Moreover, by knowing at what cone he burns his brick he can talk intelligently with other manufacturers and compare the refractoriness of materials used.

In beginning the use of cones an assortment of several numbers will have to be ordered and these set in the kiln to ascertain what is the proper cone for the clay. Red-burning surface clays for common building brick are generally well burned at cone 08 to cone 1; limey, buff-burning clays, at cone 06 to 3; shales for paving brick, cone 2 to cone 8; fireclays for face-brick or paving brick, cone 2 to cone 8; clays for No. 2 firebrick, cone 6 to cone 10; clays for No. 1 firebrick, cone 8 to cone 18.

The burner should see that the right cones are placed in the kiln as directed. In down-draft kilns, properly managed, it will only be necessary to place the cones, regularly, in the lowest peep-hole, two courses of brick above the bottom, though when first beginning the use of the cones it is interesting to place them in different parts of the kiln, not for observation during burning, but for inspection afterward in order to know the variation of temperature in different parts

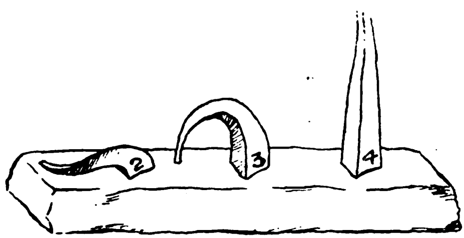


Fig. 6.

of the kiln and the range of heat that the brick will stand. Fig. 6 shows a set of cones taken from a kiln wherein the burning was finished at cone 3.

The cones should be stuck upright with stiff clay, upon a burned brickbat, as shown in Fig. 7, and should have a brick over them for protection from the direct action of the flames and the deposition of ash from the fuel. Three cones of consecutive numbers should be placed in a row with the numbers in order, the middle cone being the one that it is desired to have bent over until its point touches the brick at the finishing of the kiln. The cones should be placed in both ends of the kiln about three feet from the casing, or at such distance as to be clearly seen from the peep-hole.

TRIALS.

In burning certain kinds of brick, such as flashed brick and glazed brick or pipe, the burner should see that trial pieces are placed in kiln where they can be reached. These trial pieces have holes in them so that they can be pulled out

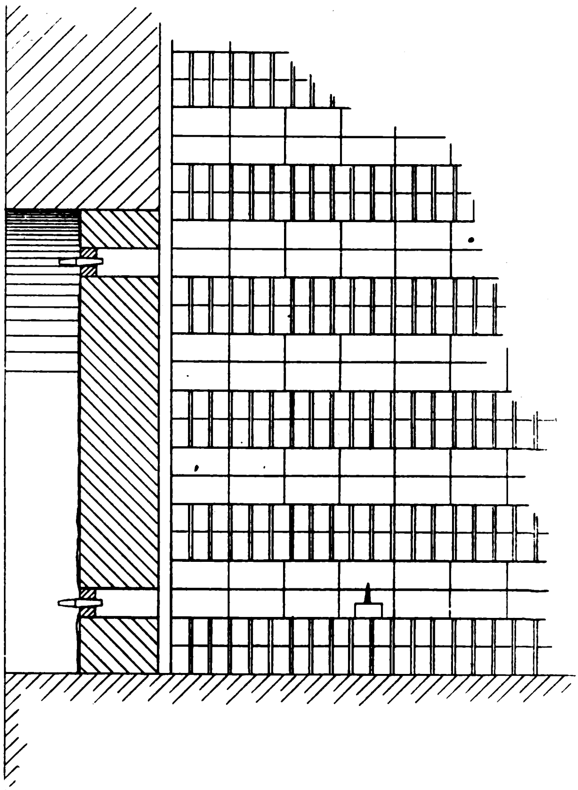


Fig. 7.

with a hook. They may be set on top of the brick and drawn out through the vent holes in crown, and also in both ends of kiln and drawn out through a hole provided for the purpose in the door casing above the lower peep-hole. Even where trials are used for determining the finishing point, the cones should be used for determining the proper temperature for salting or for pulling trials.

CLOSING KILN.

As soon as the kiln has been filled the doors should be cased up with two courses of brick, 8 inches each, laid on their faces. The inner course may be built up by the setting gang, or by the burning gang, or by extra help under the direction of the burner. The putting in of the outer course, including first the daubing of the inner course, should be attended to by the burner. These courses of brick can be laid up dry, and then each well plastered over with mortar composed of about one part of fine clay to three parts sand. This can be put on with a trowel or with the hand. When cracks appear in the outer plaster they can be closed up with a thin paste of clay and sand or with a lime wash, put on with an old broom.

The burner should also see that the covers over the vent holes are tight and that all cracks are properly daubed up. He should have the furnaces made ready for starting the fires just as soon as the casings have been put in, so that there may be no delay.

MEASUREMENTS.

As soon as the kiln is ready for burning, either before or immediately after the fires have been started, measurements should be taken of the distance from the upper surface of the kiln crown, or of the tile or casting covering the vent holes, to the tile placed upon the highest course of the setting. These meausrements are to be entered in the kiln record books as a basis for future measurements of settle during the vitrification period. It is perhaps more accurate to take these measurements from some fixed, unvarying point rather than from the surface of the crown. Sometimes the measurements are taken from a straight edge resting upon the kiln brace rods. Generally, however, it answers every purpose to take the measurements from the crown. The crown may raise somewhat when hot and the measurement not indicate the exact settle of the brick; but it is comparative results that are wanted, and as the variations of the crown would be much the same during every burn, the progress of the firing during the vitrification period is shown by these measurements.

The apparatus for taking these measurements is shown in Fig. 8. It consists of a round or square rod, ⅝ in. diameter.

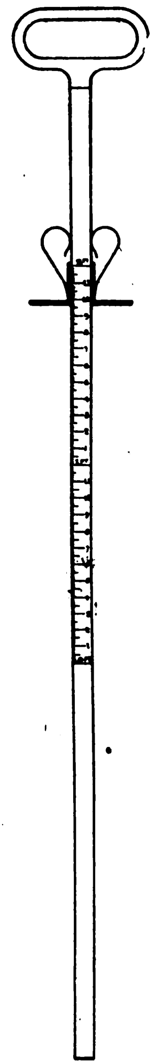


Fig. 8.

having a scale over which is moved a disc held in place by springs.

CHAPTER III.

Watersmoking Period.

STAGES OF BURNING.

The practical brickmaker recognizes three distinct stages of the operation of burning a kiln of brick—the watersmoking, the raising of the heat up to incandescence, and the shrinkage. These three stages, also, are enough to serve our purpose in preparing this treatise. No single word can be selected that will signify all of the changes that take place in the clay during any of these periods, though the old term, "Watersmoking," is quite accurately expressive of the first process, the driving out of the hygroscopic water—that is, the water still contained in the pores of the clay after air drying. The other two periods we shall term Oxidation and Vitrification, the names referring especially to the culminating action or condition of each period. No distinct line of demarcation can be drawn between these periods, as one process overlaps the other—that is, some of the actions in each period, caused by the increase of temperature, begin before all the actions of the preceding period have terminated. The temperatures given in the "Kiln Records" as limiting these periods are for the most part arbitrary and are for the purpose of securing definite, uniform expression of terms and for carrying out the system of burning herein laid down. In the oxidation and vitrification periods especially, the physical and chemical actions are very complex and not clearly understood by ceramic chemists. Enough is known, however, to require, in a more elaborate and scientific treatise than this, several subdivisions of these periods.

WATERSMOKING.

The first stage of the burning, the removal of the hygroscopic moisture, the water that is contained in the pores of the clay, even after drying, is one that often has an important bearing upon the final results. In this operation may be produced damages to the brick that no subsequent operation can remedy and that may lessen or destroy their market value. Some of the results of improper watersmoking are "scumming"—a whitewash upon the surface—checking and softening, causing damage to shape. Scumming and checking are more frequently produced in the drying of the brick, whether by natural or artificial means, but are also often produced in the kiln-drying or watersmoking.

Many burners think that all that is necessary to insure watersmoking without damage, is to go slow and take a long time for the operation. Too much time spent in watersmoking may seriously reduce the capacity of the plant, or require an unnecessarily large investment in kilns, as well as delay other operations of the factory and embarass the selling department. Moreover, slow evaporation of the hygroscopic water, with insufficient draft, is one way to produce scum upon the brick. This scumming is often aggravated by the use of sulphurous fuel during the watersmoking, but slow drying and poor circulation will produce it, whatever may be the source of heat, if the clay contains much soda, potash, lime or magnesia. There are few brick clays that will not scum, or effloresce under favorable conditions.

Slow raising of the heat is often made necessary by insufficient draft, caused by a cold, damp kiln bottom, or improperly proportioned flues or stack. Defects of kiln construction cannot be considered here. They should be referred to a competent engineer, as should also the installation of artificial means of inducing draft and decreasing the time of burning.

No specific directions as to draft or rise of heat can be given that would be applicable to every case, or to any large portion of cases, but a method of procedure and record of progress is here laid down that will enable anyone to conduct this stage of the burning, under his own conditions, in the least time that it can be done without damage to the brick. In order to secure the best results in this, as in all the other stages of the burning, one should provide means to ascertain just what he is doing and just what progress is being made, and, at regular intervals, should make an accurate record of his observations. In this way alone can knowledge be acquired that will lead to improvement and to a mastery of every operation. It is for this purpose that this treatise has been prepared.

The apparatus necessary for the controlling of the watersmoking are:

1. Draft Gage.
2. Watersmoking Thermometer.
3. Moisture Testing Rod.

DRAFT.

The brickburner should have a clear conception of what draft is and of the laws which govern it, and he should also understand the importance of having the proper draft at every stage of the burning in order to secure the best brick in the least time and with the least consumption of fuel. Draft, the suction of the air through the furnaces and kiln and out of the stack, is the pressure of the air outside through the furnaces upon the air in the stack. This pressure is caused by the difference in density or weight of a column of air having the same volume as the stack, outside of the stack, and the weight of the air in the stack. This difference in density or weight of the columns of air outside and inside of the stack is due to the difference in temperature, the warmer air in the stack being the lighter. The higher the column of air the greater will be the absolute difference in the weight of the columns, hence, the greater the pressure or draft of air going into the furnaces. Thus, we see that the pressure of the air into the furnaces, or the strength or velocity of the draft, depends upon two factors, the height of the stack and the temperature of the gases in the stack. The higher the stack and the higher the temperature in the stack the stronger the draft, or the greater the velocity of air entering the furnaces. Beyond about 500 degrees F. the temperature of the gases in the stack—that is, the mean temperature from top to bottom—has little influence upon the draft. The area of the stack may be so large as to retard the draft, but the stack may be as high as practicable with an increased advantage.

Too strong a draft means an excess of air entering the furnaces. A large excess of air is needed during the watersmoking and oxidation periods, but during the vitrification period when the draft is strongest, on account of there being at this time the highest temperature in the stack, any excess of air beyond that needed for combustion of fuel causes an unnecessarily large consumption of fuel in order to heat up this excess of air. The waste of fuel in brick burning comes almost entirely from an excess of air. Hence, practical economy requires that means be provided for measuring the draft at all times and for checking the draft during the later stages of the burning.

DRAFT GAGE.

The draft gage is a valuable instrument for use throughout every stage of the burning. It should be connected with the kiln as soon as fires are started and observations and records made at frequent intervals until the burning is finished. The apparatus is so simple that anyone can use it. It should be placed upon every form of kiln except the up-draft. No one who has ever used the draft gage would again burn a kiln without one. The use of the draft gage does not insure economical burning, but it affords an easy means of controlling waste of fuel, especially when used in connection with the simple apparatus, described further on, for determining the composition of the kiln gases.

It will be ascertained by the draft gage that there is generally insufficient draft during the watersmoking and oxidation periods and too much draft during the vitrification period. The former condition adds unnecessarily to the time of burning, as well as often doing injury to the brick; the latter condition is wasteful of fuel by admitting a large excess of air. When these facts are known and their importance realized proper correction will be made and time and money saved. Also by the use of the draft gage leaks in the kiln and flues can be detected and remedied. Moreover, a sudden rise of wind will sometimes double the draft. This will be plainly shown upon the gage and the dampers can be regulated accordingly.

The draft gage in its simplest form is a U tube, filled with water or other liquid. One end of the tube is left open to the atmosphere and the other end is connected with the kiln or flue of which the draft is to be measured. The difference in level of the liquid in the two legs of the tube indicates the amount of pressure above that of the pressure of the atmosphere. This difference in pressure is very small and would be hard to measure in the case of brick kilns, hence, we make use of the more elaborate forms of apparatus illustrated and described herein.

There are several types of draft gages in use, but the two that are most practical for down-draft kilns are the Seger draft gage and the horizontal gage, with inclined tube.

THE SEGER DRAFT GAGE.

This draft gage, shown in Fig. 9, was designed by Dr. Seger many years ago and is still the favorite gage for many uses, such as on down-draft, periodical kilns, steam boilers and chimneys. It consists of a U tube expanded at the ends into large tubes of equal size, the diameters of the larger

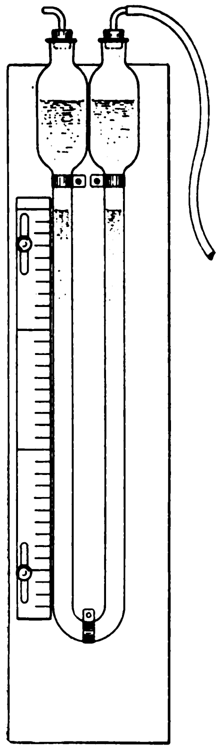


Fig. 9.

and smaller portions being accurately calibrated to a ratio of 20 to 1. The tube is fastened to a board, as shown, which also carries a scale running parallel to one leg and which can be moved up and down by means of the slits and set-screws, for adjusting of the zero point. The tube is filled with dark colored phenol and a clear saturated solution of phenol and water. The point of contact of the two liquids is adjusted exactly at the zero point of the scale. The divisions on the scale are in millimeters of water pressure. By reason of the great ratio between the diameters of the small and large portion of the tube and also of the fact that the two liquids have very nearly the same specific gravity, the apparatus is very sensitive and accurate, a slight variation in pressure being easily noted on the scale.

The enlarged openings of the tube are closed by rubber stoppers, into which are inserted glass tubes. The right-hand

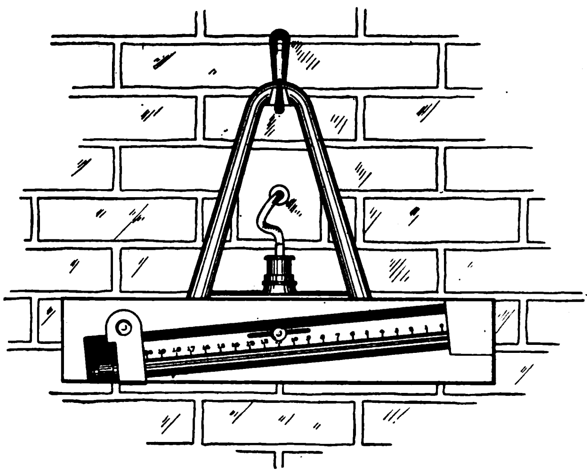


Fig. 10.

leg is connected, by means of rubber tubing, to the kiln chamber or flue, of which the draft is to be measured, and the left-hand leg is open to the atmosphere.

The apparatus is enclosed in a case with a glass front and should be hung perpendicularly on the kiln, near the point of attachment.

INCLINED TUBE DRAFT GAGE.

This gage, shown in Fig. 10, is a modified form of that commonly used on continuous kilns in Germany. A similar gage has been used for many years in this country on all plants of the Hydraulic-Press Brick Company. This consists of a metal box suspended upon a knife edge to a hook in the kiln wall, so as always to hang level. On the front of the box is a glass tube at an inclination of about 10 per cent from the horizontal. One end of this tube is connected to the box by an air-tight stopper and the other is open to the air. On the upper side of this tube is a scale which reads in millimeters of water pressure. The gage is filled with colored petroleum to the zero point of the scale. The air space in the box above the petroleum is connected by means of the rubber tube to the kiln or flue of which the draft is to be measured. By reason of the glass tube being so near the horizontal slight changes of pressure are easily noted.

LOCATION OF DRAFT GAGE.

The draft gage should always be connected at the same place on the kiln, and, in the same position on all similar

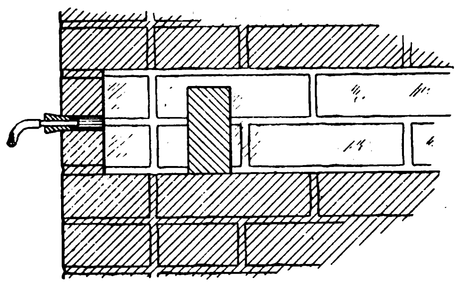


Fig. 11.

kilns, through a permanent opening in the kiln wall. This can be at any place convenient for reading. A good way to connect up the gage, after making a hole through the kiln wall, in the manner shown in Fig. 11, is to close the opening in the wall with a half brick, tightly cemented in the outer courses, but projecting an inch outside of the wall. This brick should have a hole through it about 1 inch in diameter, into which is placed a rubber stopper with a piece of glass tubing through the center. To prevent direct radiation of the heat against the stopper a brickbat may be placed in the opening through the wall in front of the stopper as shown. Or an iron pipe may be placed in the opening through the wall and the rubber tubing connected to it.

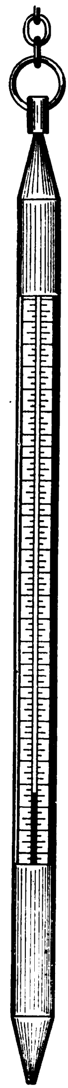


Fig. 12.

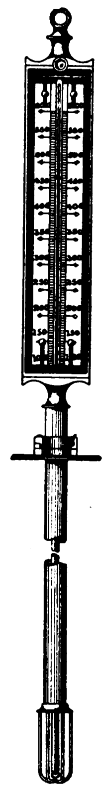


Fig. 13.

WATERSMOKING THERMOMETERS.

To obtain safe and reliable evidence of progress during the watersmoking period, the mercury thermometer is used. The thermometer for this purpose is a heavy glass tube with scale registering from 100 degrees to 600 degrees F., expanded at the top to prevent breakage in case too high temperature is accidentally reached. This thermometer is mounted in brass tubing packed with asbestos. The tubing has a pointed cap at the bottom and at the top a cap with a hole or ring for the attachment of a wire for suspending the thermometer through the crown of the kiln to any depth desired. See Fig. 12.

Another form of thermometer has an armored stem extending down through the crown and into the kiln about a foot. This thermometer, Fig. 13, is supported upon the crown by an adjustable clamp upon the stem. The scale case is a metal casting and the instrument is protected by a plate glass front. The advantage of this latter form is that the thermometer can be read without removing it. The former thermometer must be removed from the kiln and the soot wiped off before it can be read. This cooling of the thermometer makes the reading somewhat inaccurate. Moreover, if it should be raining, a drop of water upon the glass may cause it to crack.

Readings of the thermometer should be taken every three hours from the starting of the fires until the kiln of brick is thoroughly watersmoked. Records should be made of these readings in the books provided for the purpose. After using the thermometer and keeping and comparing records for a time it will be learned just how fast the heat can be safely raised with a given draft and just what temperature should be attained at every three-hour period throughout the watersmoking.

TESTING THE FINISHING OF THE WATERSMOKING.

A simple way to ascertain whether the watersmoking is complete is to run an iron rod, cold, into the bottom peep hole, in both ends of the kiln. If water is still coming from the brick, moisture will be deposited upon the rod. The rod should not be left in long enough to become heated. In cold weather, or in the early morning, moisture may be observed from the stacks, but this may be from the kiln bottom or flues after the brick have been watersmoked.

With a kiln having good draft it is possible to finish the watersmoking without attaining a higher temperature in the top of the kiln than 350 degrees, but in many cases where rapid burning is practicable the temperature in the top of the kiln may go as high as 500 degrees before the watersmoking is entirely out of the bottom. Hence, in the co-ordinate sheets in the kiln-record books, 500 degrees is taken as the limit of the watersmoking period.

HEATING UP.

Most clays will stand heating up rapidly after the watersmoking until a temperature of about 1,200 degrees F. is

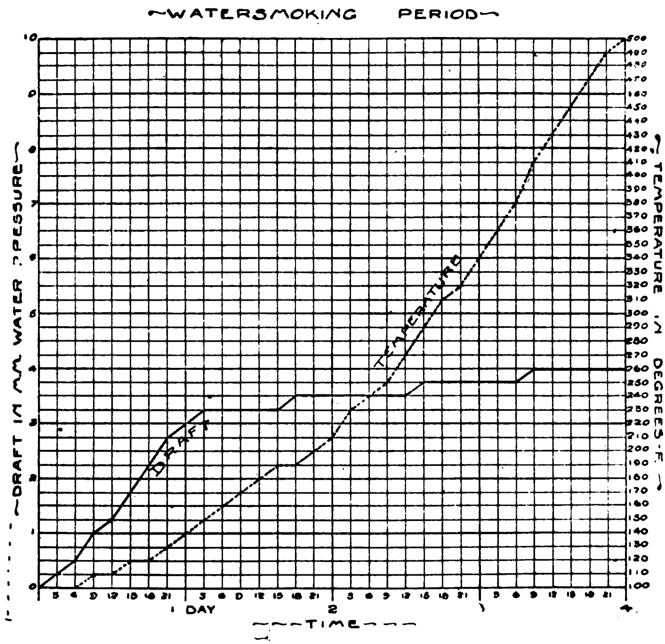


Fig. 14.

reached, but there are a few clays that, if fired heavily at the close of the watersmoking period, will pop and fly into pieces, though a strong draft will generally prevent this. The rate of heating must, therefore, be determined for each special case.

It is best first to go slowly and safely, and with each succeeding kiln to gradually increase the rate of heating a little, keeping accurate records, until the maximum rate of safe progress has been attained.

PLOTTING THE CURVES.

In Figure 14 are shown draft and temperature curves during the watersmoking period. The curves in the illustration are arbitrary and not made from an actual case in practice. The curves are plotted by the bookkeeper upon the co-ordinate sheets in the kiln-record books from daily report cards filled out by the burners and left at the office at the close of each day's work. These curves constitute a part of the permanent record of every burn that is essential to the establishment of a positive, reliable system and to such improvement in quality and economy as is being sought after by most brick manufacturers.

CHAPTER IV.

Oxidation Period.

The second period of the burning, extending from the stage at which the hydroscopic water has been completely driven off to that at which the shrinkage of the clay, or settle of the brick, begins, we have called the oxidation period. This name more accurately represents the culminating action of the period, the conversion of the ferrous oxide and the sulphides into the higher or ferric oxide that gives the bright color, red or buff, desired in brick for facing. The attainment of color is not the only purpose of this oxidation, as we shall see, but it is the one most commonly considered by manufacturers of building brick. This change is effected by the absorption of oxygen from the air admitted to kiln in excess of that required for combustion. Fifteen hundred degrees is taken as the arbitrary limit of this period on the co-ordinate sheets of the kiln record books for convenience of definition. Most clays would undoubtedly be oxidized at a somewhat lower temperature and some may require a higher temperature for complete oxidation. The whole period, however, is one of oxidation requiring a large amount of air in the kiln in excess of that required for combustion of the fuel.

This period might be divided into several stages, representing the different chemical changes that take place, not always in definite succession, but one overlapping the other. The chemistry of burning clays into brick is not clearly understood in every particular, but the principal changes that take place during the oxidation period are, as described by Orton:

1. Combustion of carbonaceous matter.
2. Combustion of sulphur, from pyrites.
3. Dehydration of kaolinite, the driving off of the water chemically combined with the clay base.
4. Decarbonization of carbonate minerals.
5. Oxidation of the ferrous oxide, and sulphide into ferric oxide and ferric sulphate.

These actions are given in the order in which they are believed to take place, though more than one action may be going on at the same time, that is, before any one has been completed the succeeding one has begun. Moreover, few clays contain the minerals necessary to produce all of the actions, at least to an appreciable degree, though there are probably no brick clays, in which most of these changes do not take place as outlined above, except perhaps the purest fireclays.

In some clays, more especially shales, the amount of carbonaceous matter is so great that its combustion must be carried on very carefully or serious results will occur. In extreme cases this carbon will take fire and ruin the brick unless the supply of air is shut off or restricted until the carbon has slowly burned itself out. Fortunately, in most clays the amount of carbon is so small that its combustion takes place without any special precaution.

Many clays contain grains of pyrites, sulphide of iron. In the making of some kinds of brick, such as the iron-mottled flashed brick, this impurity is desired and sought after, but for making clean solid colors the clay should be free from pyrites. At a temperature of 750 to 1,100 degrees, a portion of the sulphur is consumed. The escaping sulphurous gases, by their movement through the pores of the clay and their strong affinity for oxygen, hold back other chemical actions and retard the advancement of the burning. Moreover, an extremely sulphury clay may cause cracking and swelling, if heated up too rapidly, even in an oxidizing atmosphere.

The base or clay substance of all clays is the hydrous mineral, kaolinite, a compound of silica, alumina and water. The water is chemically combined and is only released when the clay is heated to a temperature of 1,000 to 1,200 degrees. The amount of this combined water in clays varies from 3 to 14 per cent. The removal of this water is necessary before subsequent changes can take place, but its removal causes no disturbance, merely leaving the clay more porous or open and in better condition for the absorption of oxygen.

There are four carbonate minerals commonly found in clays: carbonate of lime, carbonate of iron, carbonate of magnesia, and dolomite, which is a carbonate of lime and magnesia. All of these minerals are not often found in one clay, but there are few brickmaking clays, except high-grade fireclays, that do not contain at least one of these carbonate minerals.

All who use drift clays, clays of glacial origin, are familiar with limestone pebbles and the trouble they cause. In the burning of such clays the limestone pebbles give up their carbonic acid and become lime, which, upon exposure to moisture, hydrates energetically, increasing in volume two or three times, causing the rupture of the brick or the exposure of lime specks by "popping." In clays which contain the lime in a finely divided state, intimately incorporated with the clay substance, no trouble is experienced from popping or from swelling of the brick upon exposure to moisture, if the brick have been hard burned. Some light burning clays, as those of Milwaukee, owe their color to the presence of lime, which at high temperature unites with silica and alumina and iron, forming a silicate compound in which the red color of the iron is masked. Bricks from these clays have a cream or light yellow color. Whatever may be the condition of the carbonate of lime in the clay, it must be decarbonized, the carbonic acid expelled, before oxidation can be completed. This decarbonization of lime has been found to be accomplished at from 1,000 to 1,600 degrees.

Carbonate of iron is of frequent occurrence in clays, especially shales. There are few shale banks that do not contain more or less of hard plates or kidneys of iron carbonate. Some of these can be rejected, but many of them get into the pans and are ground up. The presence of this carbonate in the brick may cause trouble on account of the escaping carbonic acid retarding the oxidation, unless sufficient time is given for the decarbonization before raising the temperature to the point of vitrification. Professor Orton determined that the carbonic acid is driven off from iron carbonates at about 800 degrees.

Magnesium carbonate and dolomite are of less frequent occurrence in clays and the percentages are smaller. Hence not much attention has been given to their decarbonization. This takes place at 750 to 1,100 degrees, and, like the preceding changes, can not be postponed.

The time necessary to effect these changes varies with every clay, hence the importance of a systematic investigation in every case, in order that no brick be damaged by improper oxidation and no time wasted. As has been shown, the first part of the oxidation period is given to decarbonization, desulphurization and dehydration. The expulsion of these volatile matters has left the pores of the clay open and free to absorb oxygen. The complete oxidation of the ferrous oxide and the ferrous sulphide can not take place until these preliminary steps have been taken, until these carbonaceous and sulphurous gases have been driven out. Proper oxidation requires not only a sufficiently high temperature, but a kiln atmosphere free as possible from carbon and sulphur and having a large amount of oxygen. If this part of the burning has been rushed too rapidly, and the temperature has been raised to the vitrification point before the oxidation has been completed, the pores on and near the surface of the brick will be closed and the oxidation of the center of the brick can not take place. The result is that the ferrous iron in the interior of the brick, which fuses at a lower temper-

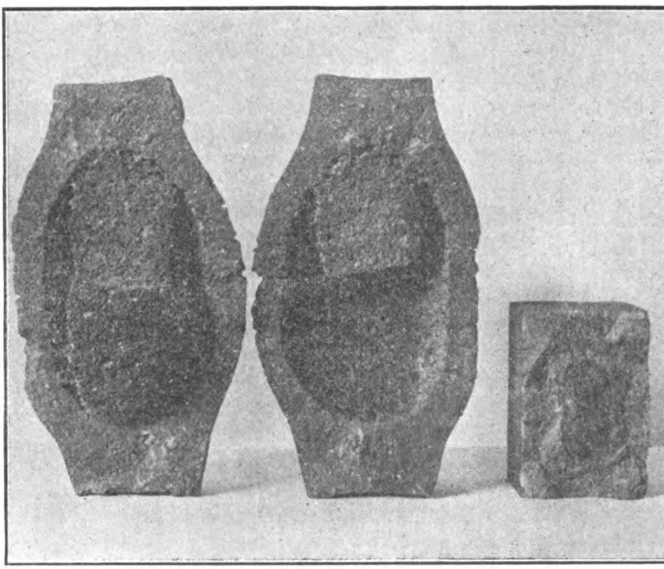


Fig. 15.

ature than the ferric iron of the exterior, will form a slag evolving gases with such energy as to cause the swelling of the brick into a worthless mass, having an outer hard shell and an inner black spongy core, as shown in Fig. 15. In some cases, as shown in the right-hand brick of this figure, the swelling may not have taken place, but the brick has been so weakened as to be unsuitable for the purposes for which it was made.

We are indebted to Professor Orton for the first and only clear and logical exposition of the causes that produce swelled or black-cored brick. The paper giving an account of his investigations of this subject, under the title, "The Role Played by Iron in the Burning of Clays," was first published in Vol. V of the "Transactions of the American Ceramic Society," and should be read by every brick manufacturer and burner. It does not pertain to the purpose of this treatise to go deeply into the subject; in fact, this could not be done by any one without making use of the matter so clearly expressed by Professor Orton. Enough has been said to show the importance of careful attention to this period of the burning. A method of procedure is here laid down that will ensure safe and positive results in the least possible time and that when once established does not depend upon the skill and knowledge of any one man.

DIRECTIONS FOR CONDUCTING THE OXIDATION PERIOD.

1. Keep a strong draft. Take observations of the draft gage every half hour. Record the readings of the draft gage as provided every three hours.
2. Keep clean, open fires, firing light and often.
3. Increase the temperature regularly and constantly, but slowly, as experience has shown to be necessary with the clay you are burning.
4. Take observations of the temperature every half hour, or oftener. Record the readings of the pyrometer every three hours, as provided.
5. For a few burns, until it has been ascertained what draft and temperature is best, at every three-hour period, in order to get the quickest results without damage, trial brick should be drawn, and broken through the center after they have cooled somewhat.
6. With very bad material, such as black bituminous shales, the safe combustion of the carbon may require the furnaces to be closed and firing ceased, after the carbon has begun to burn in the brick, until this carbon has slowly burned itself out. Continued firing, or even the admission of air through the open furnaces, may cause such a conflagration in the kiln as to ruin the brick. In more moderate cases, in order to oxidize such materials, it may be advantageous during this period to raise the heat to a safe point, say 1,100 to 1,200 degrees, and then let it cool down to about 700 degrees, repeating this alternately for a few times. The cooling down in a clean oxidizing atmosphere sometimes causes greater

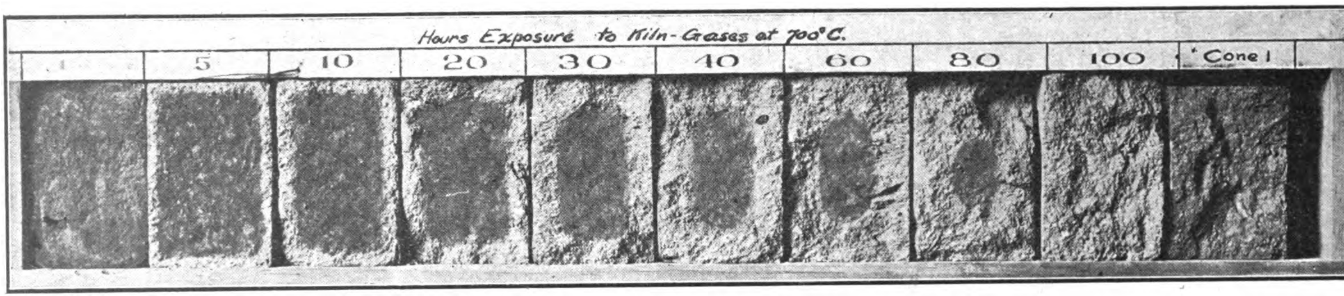

Hours Exposure to Kiln-Gases at 700°C.
5
10
20
30
40
60
80
100
Cone 1

Fig. 16.

progress than the same time spent in firing up with the necessary carbon gases from the fuel.

MEASURING PROGRESS DURING THE OXIDATION PERIOD.

The progress of the oxidation can be ascertained by the pulling out of bricks from the kiln at frequent intervals. The first trials pulled out soon after the beginning of this period will show, upon breaking the brick, a black fracture with a grayish border. From this point on the progress is to be noted by the decrease in size of this black portion, the gray margin increasing and the black core growing less, until it finally disappears from the center. This is clearly shown in Figure 16, photographed from a set of trials. This method of noting the progress is interesting, but it is inconvenient and not practical for every day use. The trials should be full-sized bricks and enough of these can not be well placed in the kiln and be easily taken out. A duty that is disagreeable and inconvenient is apt to be neglected. Hence, another and more convenient method of ascertaining the progress of the oxidation period should be introduced. This can be accomplished, after a few trials, by measurement of the draft and temperature at regular intervals.

When it has been determined for any clay just how rapidly the temperature can be increased, and just what draft and temperature is best for each three-hour interval, and just how long it takes to complete the oxidation, the progress can be controlled by the draft gage and pyrometer and time-piece. The draft gage has already been described. A suitable instrument for measuring temperatures, one that is cheap and practicable for brickyard use, and accurate up to 1,600 or 1,800 degrees, and does not often get out of repair, is not easy to find. The following are the most practical pyrometers that have been made for the purpose:

THE METALLIC PYROMETER.

The most approved metallic pyrometer is that of the Gauntelett system, shown in Fig. 17. The construction of these instruments is based upon the expansion and contraction of two tubes of different metals. The difference in expansion of these two tubes when exposed to heat is transferred by a movement to the pointer indicating the tempera-

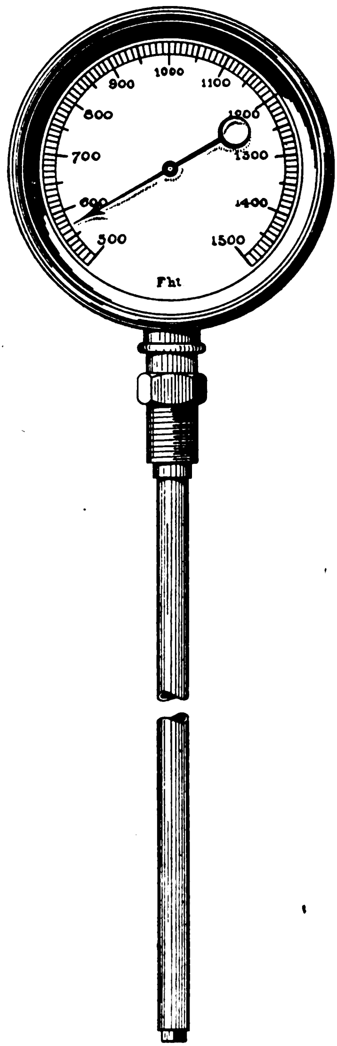

800
900
1000
1100
700
1300
1400
500
1500
Fht

Fig. 17.

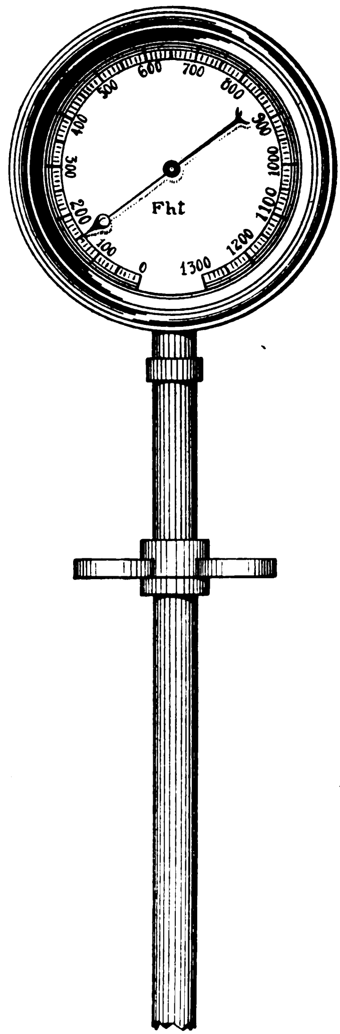

600
700
500
400
300
200
100
0
1000
1100
1200
1300
Fht

Fig. 18.

ture upon the dial. These pyrometers are designed for temperatures from 500 to 1,500 degrees. Repeated use, however, above 1,200 degrees changes the nature of the metals and renders the instrument unreliable, and makes repairs or adjustments necessary. Moreover, 1,500 degrees, while a high enough range for the oxidation period in most cases, is too low a limit for safe use.

GRAPHITE PYROMETER.

The graphite pyrometer, Fig. 18, patented by Edward Brown, has for an expansion stem an iron tube enclosing plumbago bars. Many of these pyrometers have been sold and they are very satisfactory for temperatures up to 1,200 degrees. They can be occasionally used up to 1,400 or 1,500 degrees, but constant or repeated exposure to these high temperatures alters the expanding property of the iron and plumbago. Means have been provided for making adjustment of the pointer to correspond with the change in the iron and graphite. This pyrometer is used to good advantage on brick kilns, for want of something better. It is all that could be desired for temperatures up to 1,400 degrees, but this is too low a limit to get all the benefit to be derived from a pyrometer in brickmaking, even during the oxidation period. This pyrometer is also made with a self-recording dial on a twenty-four-hour chart.

THERMO-ELECTRIC PYROMETER.

The thermo-electric pyrometer for measuring high temperatures, according to the principle of Professor Le Chatelier, of Paris, and made in Germany by Mr. Heraeus, is now well known to the clayworkers of America. The principle involved in the construction of this instrument is the conversion of heat into an electric current and determining the degree of heat by a suitable devise indicating the electromotive force of such a current. This instrument consists essentially of a thermo-couple made by fusing together two wires, one of pure platinum and the other of an alloy of platinum with 10 per cent. of rhodium, and of a galvanometer connected with the thermo-couple at any convenient distance. To prevent injury to the couple, the wires are enclosed in porcelain tubes. The junction of the two wires generates a slight electric current when heated, which is transmitted to the galvanometer. The pointer of the galvanometer moves over two scales, one of which denotes the electro-motive force of the current in microvolts—which makes it possible that the readings of the instruments can be checked—while the second scale gives direct readings of the degrees of temperature.

The pyrometer can be used to 1,600 degrees Centigrade, 2,920 degrees Fahrenheit, about cone 24. It is the most successful instrument for measuring high temperatures that has ever been devised for general use and it has had a large sale in the past few years. One finds it in a good many clay-

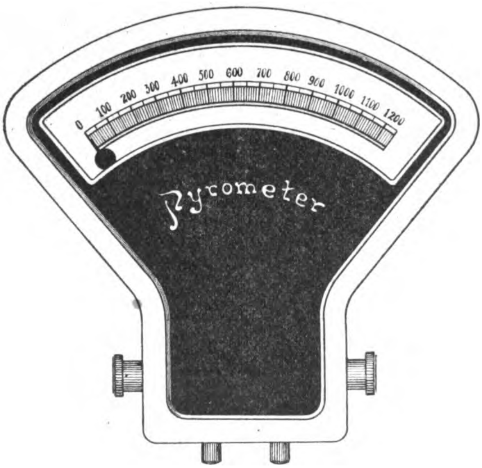


Fig. 19.

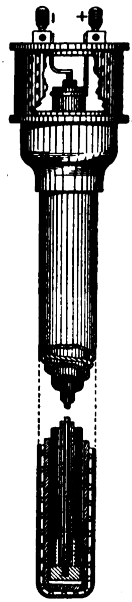


Fig. 20.

working plants, including a few brickyards. The objection to its general use is its high price, especially the expense of the couples on account of the rare and dear metals used in the wires. Recently, however, a pyrometer has been constructed on the same principle, but using a cheaper couple, Figs. 19 and 20.

THE CARBON-NICKEL THERMO-ELEMENT.

This new thermo-element, Fig. 20, consist of a tube of specially prepared carbon and a wire of pure nickel. Such a carbon can, without undergoing any change whatever, be heated to the highest white heat, if the entrance of air or oxygen is prevented. This is secured by surrounding the carbon through its whole length with a porcelain tube, in which the carbon, after the original small quantity of oxygen present is consumed, glows in an atmosphere of perfectly indifferent gases. This porcelain tube may be surrounded with a strong iron protection pipe in which it is packed with a soft asbestos filling, or it can, when employed in places where, owing to the direct flash of the fire, the burning out of the iron pipe is to be feared, be used without this iron covering.

Since nickel wire is easily attacked by carbon at a white heat, it has been provided with complete insulation by making the metallic connection through an iron piece which also receives the end of a second porcelain tube surrounding the wire closely. A head with clamps forms the upper terminal of the elements, which for the purpose of cooling is perforated like a sieve.

Such an element can be regarded as durable and not requiring any adjustment, up to 1,250 degrees Centigrade, 2,282 degrees Fahrenheit. It possesses nearly three times the electro-motive force of the platinum element and, moreover, possesses the advantage of a smaller and unchangeable resistance under cold and warm conditions. These characteristics are of the highest importance in the construction of an exact measurer of electro-motive force. They make possible the production of a galvanometer with a resistance of 400 to 500 ohms, so that neither the length of the conducting wires, nor the proper resistance of the elements nor the temperature of the room in which the galvanometer is placed, exercises any influence over its exactness. This carbon-nickel electric pyrometer can be bought for a little more than one-half the price of the Le Chatelier pyrometer. Its range of temperature is high enough for the entire burning of most brick clays and it will answer for the complete oxidation period of any clay.

OXIDATION CURVE.

The manner of plotting this curve is shown in Fig. 21. The draft and temperature curves in the illustration are not taken from any case in practice, but approximate what is believed to be proper in many cases. The ideal curve, which is always aimed for, varies with conditions, is different in almost every case and must be learned for himself by every manufacturer.

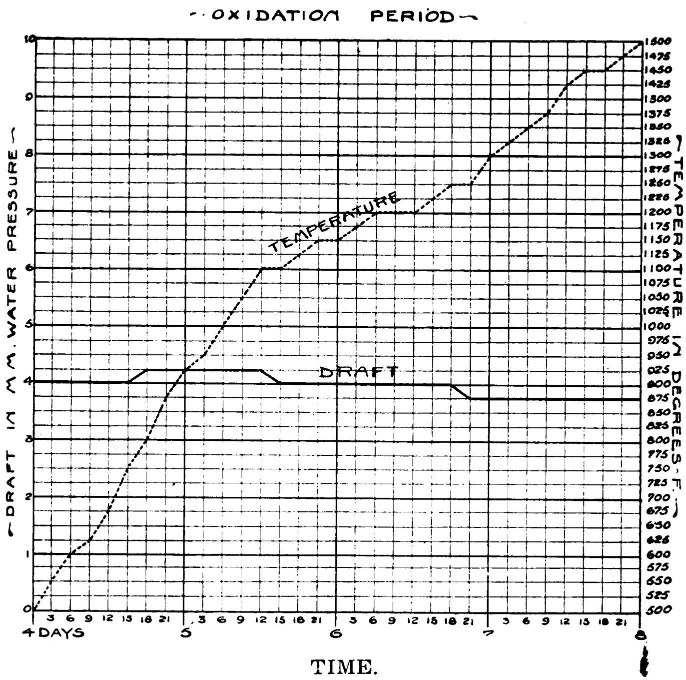


Fig. 21.

The purpose of this short treatise is to outline a course of procedure that must, if conscientiously and persistently followed, result in the mastery of all burning problems.

CHAPTER V.

Vitrification Period.

The last stage of the burning takes its name from the final, culminating action of the whole process, the vitrification or hardening of the claybody to the point where it attains its maximum density and strength and resistance to abrasion and to absorption of water. This does not mean, as the word would indicate, that the clay had been formed into a solid homogenous body like glass. Vitrification, as applied to clay, has been given a special meaning to designate that condition of the burned product in which the ware or brick is at its best for most uses, will best answer sanitary requirements and best resist disintegration. The burning is carried beyond this point only by accident or inattention. To the practical man this period is a period of shrinkage, and his aim is to get the greatest amount of shrinkage or settle in his kiln without deforming the brick or causing them to sink into one another. He knows that complete vitrification means the complete shrinkage of clay and that however long the kiln may be fired, if the full amount of settle has not taken place, the brick, except perhaps a portion of them, are not burned to the proper degree of hardness. He does not need to know the exact chemical and physical changes that take place in the transformation of the clay into a hard, durable body. In fact, not even the most learned ceramist understands thoroughly the nature and order of these chemical actions that produce the physical changes in the brick during this period. It is not essential to our present purpose to even attempt a resumé of what has been learned of the chemistry of the vitrification of clay bodies. We are interested here only in the proper management of the kiln during this period in order to obtain the largest percentage of first grade brick with the least expenditure of fuel and time. To accomplish this, we must carry on the same method of procedure that has been laid down in previous chapters and complete the system of observing and recording, at frequent intervals, the progress of the burning.

When the brick have been properly oxidized, the burning can generally be carried to completion without serious damage; and yet to get the best results, hot and hard work and skillful attention are still necessary. At the close of the oxidation period, which we have placed in our kiln records at 1,500 degrees F., the brick should be uniform in color through its whole cross-section. This color will be a salmon or pale red in red-burning clays and a yellow in buff-burning clays. The brick will have begun to shrink and get hard, but will still be too soft for any useful purpose. Their value as a constructive material is still to be given them. Many of the impurities have been burned out and volatile matters driven off. Now must be built up at higher temperatures, from the minerals of the clay, the homogenous silicates that give permanence and indestructibility to clay bodies.

No marked settle has yet been obtained. The temperature has been kept down by the necessity of admitting large quantities of air to carry on the oxidation. A large excess of air being no longer necessary, the kiln doors may be kept tight and heavier charges of fuel made. Moreover, after the setting is well under way, the draft may be checked by gradually lowering the damper in the main draft flue. In this manner the temperature will be raised and a settling heat maintained without undue consumption of fuel. There are so many different kinds of furnaces in use on brick kilns that no definite directions can be given for their operation. One fact, however, has been definitely settled by expert burners, and that is that in down-draft kilns, economy of fuel and labor, and generally also of time, requires that the draft be checked during the vitrification period. This may mean more careful watching, but it certainly means the handling of a less amount of fuel. The reason of this is plain: The kiln has too strong a draft when the kiln and flues are red hot. A large amount of air in excess of that required for combustion is drawn through the furnaces. This unnecessary air cools down the gases or requires more fuel to keep up the heat. It is unsafe, however, to trust the dampering of a hot kiln to an inexperienced man, with no controlling apparatus to guide him. Trouble from this source has led some brick manufacturers to discard the use of the damper entirely, preferring to waste fuel rather than to run the risk of overburning or of reducing actions. Such a method should not be satisfactory to those who are striving for the best results, not only in quality of product, but in what is becoming of increasing importance to the brick industry, the lowering of the cost of production. If this little book does not show how this can be accomplished, it will have failed of its purpose.

MEASUREMENT OF PROGRESS.

There are two ways in which the progress of the burning during the vitrification period can be measured. The temperatures can be measured and recorded at frequent intervals, or the shrinkage of the clay can be measured. The latter is generally the most practical and satisfactory way. Measurement of the temperatures by means of a pyrometer is interesting and instructive and should be carried out by every manufacturer for a time, at least, during the whole burn, but nothing will take the place, upon a brickyard, of the measuring of the settle. The shrinkage of the clay is practically what the bricks are being burned for, and the progress made in this can be conveniently and accurately determined by measuring the settle.

The method of measuring settle was described in a previous chapter. The measuring rod is placed in the hole until its lower end strikes the tile which was placed under the hole upon the highest course of setting, the spring-clamp moved down until it strikes the surface from which the measurements are taken and the feet and inches read off on the scale and recorded in place provided upon the burner's report card. These measurements should be taken every three hours during the vitrification period until the burning is finished. The amount of settle from the last measurement should also be recorded, as well as the total settle. Reading of the draft gage should be taken at the same time and placed upon the card. The permanent records in the books provided for this purpose should be made every day by the bookkeeper or superintendent.

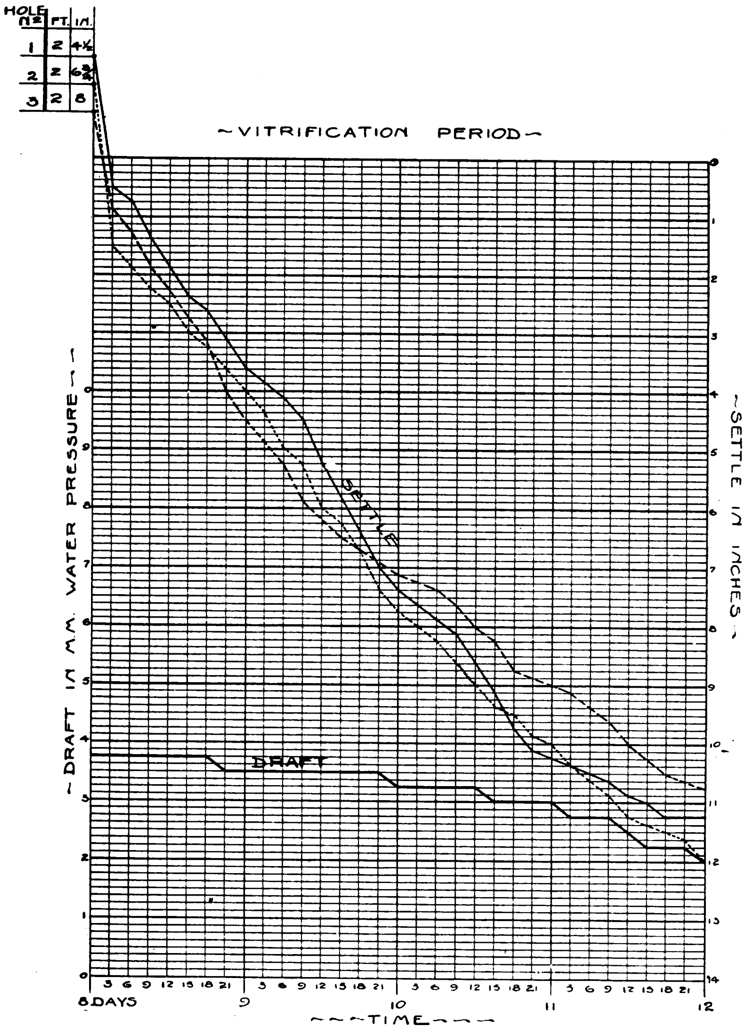
The amount of settle that is best in any given case can only be learned by trial and depends upon the character of the clay and the purpose for which the brick are to be used. There are some weak, sandy clays that shrink but little in burning; in fact there are some clays that expand under heat, the brick being larger after burning than before, but such clays are very rare and do not make the best brick. To what extent any manufacturer should carry the process of vitrification is, outside of the nature of the clay, largely a question of his market requirements. If he is making common building brick, his customers may not demand that he bring any large portion of his product to a state of complete or even partial vitrification, though in most places now the demand for harder brick for all purposes is increasing. Soft, underburned brick when sold indiscriminately will often be used where the results will be damaging, not only to the purchaser and to the brickmaker who sold them, but also to all brickmakers, since poor brick leads to the use of other material for building.

In paving brick, complete vitrification of the largest possible portion of the kiln is desired by all. Just how large a percentage of the kiln can be vitrified does not always depend entirely upon the adaptability of the kiln for the purpose nor upon the skill of the burner, but much upon the character of the clay or shale of which the brick are made. Many shales have a very limited range of vitrification temperature, that is, there is a narrow margin between vitrification and viscosity, between the production of a hard, vitreous body of the desired form, and the breaking down of the structure of the brick into a deformed and shapeless mass. Just what elements or combination of elements it is that gives the wide vitrification range is not known. The chemical analysis of a shale does not now enable us to pronounce definitely as to its adaptability for the making of paving brick or other vitrified ware. Some day we may know more about this and be able to select materials, or compound them, for vitrified ware from their chemical composition.

The face-brick manufacturer also must now produce a much harder body than formerly, as the requirements of imperviousness in brick facings is wisely increasing.

Even the firebrick manufacturer is often required to produce a harder brick, one that has reached the practical limits of shrinkage.

Thus, no matter what kind of brick are being manufactured, a more or less hard body must be produced, and the degree of hardness of most clays can be accurately gauged by the shrinkage during this vitrification period. Hence it is of great importance to watch this process closely, make frequent measurements of settle and keep an accurate record of progress, for comparison and reference in establishing the best system. Notwithstanding this, it is not uncommon to see brick being burned in down-draft kilns with no note being taken of the settle and no definite knowledge of the progress of the burning, or of the proper finishing point, except such as may be gained from pulling out trial bricks. The pulling



HOLE №
FT.
IN.
1 2 4½
2 2 6¾
3 2 8
VITRIFICATION PERIOD
DRAFT IN M.M. WATER PRESSURE
SETTLE IN INCHES
SETTLE
DRAFT
8 DAYS
9
10
11
12
TIME

Fig. 22.

out of trial bricks may be a reliable indication, to the experienced burner, of the proper time for finishing the burning, but it is such an inconvenient method that it is apt to be neglected when most needed. In any case it depends for its value upon the empirical judgment of one man and makes no record that anyone else can use.

When the proper settle has been obtained and the proper cone in the bottom of the kiln has gone down, firing should cease. The finishing point can be determined from the cones alone, but the progress that is being made up to this point during the vitrification period can best be ascertained, in most cases of brick burning, by measurements of the settle. The amount of the settle will clearly indicate whether any shift of firemen have made their proportionate amount of progress or whether time and fuel have been wasted.

The best manner of closing the kiln after the last firing must be learned in every case, and depends upon the clay, the kiln and the ware burned in it. If bright colors are desired the damper should not be closed until all the fuel in the furnaces has been burned out.

VITRIFICATION CURVE.

Fig. 22 shows the manner of plotting the curve during the vitrification period. The curve is not taken from any case in practice, but is made up for illustration. The figures in the upper left-hand corner represent the first measurement of the three measuring holes of the kiln. This measurement was taken and recorded at the time the fires were started. When the second measurement was taken, about the close of the oxidation period, the kiln under hole No. 1 had settled ½ inch, under hole No. 2, 1½ inches, and under hole No. 3, ⅞ of an inch. From this point on measurements were taken every three hours with an average settle of ⅜ of an inch. The total settle of the kiln under hole No. 1 was 10⅝ inches, under hole No. 2, 12 inches, and under hole No. 3, 11¼ inches. In burning face brick the settle should not be less than ¼ inch nor more than ½ inch every three hours, ⅜ of an inch being a good average. For common or paving brick the settle may be a little faster. The draft is shown as decreasing from 3¾ millimeters at the beginning of the period to 2 millimeters at the close.

CHAPTER VI.

COOLING.

The duties of the burner to his kiln of brick do not cease with the firing. He must see to it that the brick are not damaged in the cooling. As he has charge of the last operation in the manufacture of the brick, it is his duty to give them the highest possible market value. The brick are not ready for the market until they are cooled. It must be the study of the burner to cool the brick in such a manner as not only not to damage them but to give them the best appearance and the greatest durability possible. That brick are sometimes checked by too rapid cooling is well known, and the harder and more dense the brick, the more liable they are to be damaged in this manner. That brick are rendered more brittle, more liable to damage in the handling and transportation, is not so generally recognized, since loss from this cause is seldom placed where it belongs. Paving brick manufacturers have learned by dear experience that rapid cooling injures the toughness of the brick, and that to get the best results from the rattler test, the brick must be carefully annealed by slow cooling. Just what would be too rapid cooling in any case must be learned by trial. Cool slowly at first, and if the brick are uninjured, gradually decrease the time of cooling, making a record of the manner and time of cooling in the kiln record books by filling out the forms provided. When the safe limit has been reached in any case, a systematic manner and uniform rate of cooling can be maintained and the best results obtained in the least time.

It is interesting and instructive in establishing a system of cooling kilns, to have an electric pyrometer on the kiln during the cooling and take frequent readings. From this, one can learn just how fast the cooling takes place during any period and from any conditions. It will also be seen how rapidly the temperature falls during the earlier part of the cooling, when the brick are hottest, and how slowly it falls after the incandescence has disappeared, the rate of cooling constantly decreasing, until the brick can be taken out. There comes a time, say after the kiln has cooled to a temperature of about 300 degrees, Fahrenheit, when one becomes impatient at the slow rate of cooling, especially if his customers are pressing him for brick or he needs the kiln for setting in order not to stop his machinery. He finally tries to persuade his men that the work of emptying the kiln can be begun, and, perhaps, to convince them, he gets into the kiln himself and starts the handling of the brick; but he soon changes his mind and tells his men to let it go until the morrow, or he makes some excuse for leaving them, and becomes forcibly impressed with the long time that it takes to cool a kiln of brick down from 300 degrees to 100 degrees. If he calculates the loss of time in this, on every kiln, he will find that the wise and most profitable thing to do is to get a portable fan and blow cold air into the kiln. This fan can be placed so as to blow into the furnace nearest the door and make the kiln so comfortable that the men can go to work in it at least twenty-four hours sooner.

RESULTS OF BURNING.

The emptying of the kiln should be closely watched and defects in the setting or burning carefully studied, in order that a way may be devised of remedying them. Some system of grading should be established, adapted to the character of the product, and an approximate estimate made of the number of brick of each grade taken from the kiln, also of the amount of waste. The percentages of each grade should also be calculated. These figures should be entered in the kiln records in the spaces provided.

Notes should also be made in the record books, as provided, of the result of any changes made in the setting or in the manner of burning or in the kiln furnaces or flues. Also, weather conditions, during the burning, should be noted in the space provided, especially any unusual conditions that might affect burning operations.

FUEL ECONOMY.

Economy of fuel has been given little consideration by the brickmakers of America. Our wasteful methods of burning brick are a source of wonder to European clayworkers visiting this country. That increased competition and lessened profits, and the inevitable rise in the price of fuel, must bring us to a more careful study of economical kilns and methods, is the logical conclusion of any consideration of this subject. It will probably be a long time, however, before the continuous kiln will supplant the down-draft periodical kiln to the extent that it has done in Europe. But we should, at least, give our attention to a more economical management of the down-draft kiln. Some improvement in economy can be made by changes in the design of the kiln and furnaces, to adapt them to the conditions of any special case. This is the work of the engineer and need not be considered here. This treatise pertains only to the management of the kiln and not to its design or construction.

Waste of fuel in the management of brick kilns comes chiefly from two sources, by either not supplying enough air to complete the combustion of all the carbon, so that a portion passes through the kiln unconsumed, in the form of carbonic-oxide gas, CO, and (to a less extent) hydro-carbons, or by supplying too much air which must be heated up before the temperature of the brick can be raised. There is some loss, also, from floating particles of carbon, that form the smoke, but this loss is insignificant as compared with others. The greatest loss is from the large excess of air that is almost universally admitted to the furnaces of brick kilns and through cracks in the walls. To be sure, during a great part of the burning, the watersmoking and the oxidation, a large excess of air is necessary to remove the water and carry on the chemical changes in the clay. Hence, during these periods of the burning, economical combustion of fuel cannot be given much consideration. From the completion of the oxidation, however, any large amount of air, in excess of that required for combustion of the fuel, means so much loss of heat. It is probably safe to say that the average amount of air admitted to brick kilns, even during the vitrification period, is not less than 300 per cent., while the average should not exceed 125 per cent. This means a loss of fifty-seven per cent. of the weight of the fuel, assuming that it is average bituminous coal. The available heat of such a coal is reduced in the case of 125 per cent. air admitted, to 6,900 calories, with 300 per cent. to 2,800 calories. An important question then is, how can this be avoided?

The first step in an investigation of fuel economy is to ascertain how much fuel is being wasted. First, an examination should be made to see if an undue amount of heat is being lost by conduction and radiation from the walls and crowns, both of kilns and furnaces. Second, is there a considerable loss of heat from cracks in the walls that admit cold air? Third, is there a large loss of heat on account of kiln bottoms and flues being wet or not being insulated from the ground moisture, so that heat must be expended in every burn in evaporating water from the ground? This last loss alone may amount to several tons of coal at a burn, to say nothing of the loss of time. Fourth, is there a large amount of air admitted to the furnaces in excess of that required for combustion, or is there, during much of the time, an insufficient amount of air for combustion?

All of these questions are capable of being answered satisfactorily after proper investigation, and the facts being known, the defects can be corrected and most of the loss of fuel prevented. Where brickmaking operations, especially the burning, are under the direction of engineers, as in Germany, these matters are constantly being investigated and wasteful conditions removed. It is proposed here to discuss only the loss of fuel from faulty combustion—not enough air being admitted to furnaces, or too much. This investigation is made by analyzing the kiln gases.

Before describing the method of analyzing kiln gases for the purpose of ascertaining economy of operation of the furnace, a brief exposition will be given of the chemistry of the combustion of fuel. We will assume, also for brevity, that the fuel used is coal.

There is considerable difference in the composition of coals, but they all contain, as fuel elements, carbon, either as solid carbon or as carbon combined with hydrogen in various proportions, called hydro-carbons. The non-fuel elements, the impurities of the coal, which form the ash or clinker, will not be considered in this connection. The solid carbon and the hydro-carbons are fuel—that is, produce heat—because of their great affinity for oxygen, with which they combine vigorously and rapidly, when raised to the proper temperature. This chemical union (or burning, as we call it) of the carbon and hydrocarbons with oxygen is what produces the heat. Coals vary largely in the proportion of fixed carbon to volatile hydrocarbons. Coal having the least amount of volatile hydrocarbons is called anthracite, and, as the carbon ratio decreases, semi-anthracite, semi-bituminous and bituminous.

It is not pertinent to our subject to consider the relative fuel values of different coals, but only the economy of burning any given coal. It is evident that to burn coal—that is, to promote the union of the carbon of the coal and the oxygen of the air—a certain amount of air must be brought into close relation with the coal. Furnaces are designed to assist in bringing the proper amount of air in contact with the fuel. The amount of air required to burn a given quantity of fuel can be definitely calculated from the composition of the coal, but it is not possible to design a furnace that can be operated so as to introduce even the approximate volume of air required under any given conditions, and even the most expert and careful fireman cannot tell by his eye whether he is admitting this proper amount of air or not. He should be able to tell in most cases if he is admitting too little air, by observing the smoke and the flame passing out his kiln, but how much excess of air he is admitting he can only guess at. The waste of fuel in brick burning from excess of air is enormous, and yet few realize it, or if they do suspect it, are afraid of the opposite danger of too little air and the reducing effect upon their brick, and no attempt is made to remedy it. It is our purpose to show how this matter can be regulated so as to get the desired results with the least possible consumption of coal.

When coal is thrown upon a fire the volatile hydro-carbons are first disengaged. These gases issue from amongst the burning carbon and if a sufficient quantity of hot air is present, burn with a transparent blue flame, producing carbonic acid gas and steam. If the temperature of the furnace is high, the gases are generated more rapidly than they can unite with oxygen, either because not enough air is present or it has been cooled down too low by the heavy charge of coal, and perhaps wet coal, and by the opening of the furnace door. In this case carbon is disengaged as a fine powder which floats in the gas, and if it comes in contact with oxygen at the temperature of ignition, burns with a yellow or white flame. If, however, it comes in contact with cold air, it passes off as smoke or is deposited as soot. Black smoke is produced by the hydro-carbons alone, and represents only a small portion of the loss of fuel in brick kilns. To prevent smoke, do not throw green coal on a hot fire, but throw the fresh coal upon a charging table in front of and above the fire, where it can dry and be partially deprived of its hydro-carbons before it is placed upon the hot fire. The hydrogen of the hydro-carbons unites with oxygen and burns to steam.

After the volatile ingredients of the coal are distilled out, there is left the fixed and the free carbon in the form of coal or coke. This burns by uniting with the oxygen of the air. If not enough air is present, it is only partially burned to carbon monoxide—CO—which escapes from the kiln unless it meets with more oxygen at a high temperature. If a sufficient amount of air is present in the furnace, carbon takes up the greatest amount of oxygen of which it is capable, forming carbon dioxide—CO_2. Partial combustion to CO produces less than one-third of the heat that is yielded by the complete combustion to CO_2. Hence, it is evident that an insufficient amount of air may cause a considerable waste of fuel. This is not so frequently the case in brick kilns, however, as has been proved many times, though it is a condition sometimes sought after in the burning of certain kinds of brick, especially the iron-mottled flashed brick for facing. In burning these brick the reducing action of the CO and hydro-carbons is more important than the saving of the fuel, though this action need not, and generally cannot, be maintained but a part of the time—for a few minutes, just after firing.

Atmospheric air is composed chiefly of nitrogen and oxygen—approximately four-fifths of the former to one-fifth of the latter, or more accurately, 79 per cent. by volume of nitrogen and 21 per cent. of oxygen. It is only the oxygen that is concerned in combustion, the nitrogen being inert—that is, taking no part in any chemical actions that occur. It is evident that a certain amount of oxygen, or a certain amount of air, is necessary to burn a given amount of fuel of any kind. Knowing the composition of the fuel, this amount of air required under perfect conditions of mixture could be definitely calculated. Thus it has been found that to burn one pound of carbon to carbonic acid requires two and two-thirds pounds of oxygen or twelve pounds of air, and to burn one pound of hydrogen to water requires eight pounds of oxygen or thirty-six pounds of air. On an average composition of bituminous coal there would be required for complete combustion of every pound of coal about 143 cubic feet of air at 32 degrees Fahrenheit. Of course, such perfect conditions could never be attained, and practically not less than 180 cubic feet of air is required to burn a pound of coal in a good furnace. In ascertaining the economy of fuel in any case we make our calculations from the percentage of air that is admitted for combustion. It has been determined that with a good furnace only about 125 to 150 per cent. of air (100 per cent. being perfect conditions) need be used. Hence, if we find that 200 to 300 per cent. or more of air is being admitted to kiln, there is a large loss of heat in bringing this large excess of air up to the temperature of the kiln.

The method of ascertaining the character of the combustion taking place in the kiln is by analyzing the gases in the kiln or before they escape from the kiln. There are two kinds of apparatus in common use for this purpose.

THE ORSAT APPARATUS.

The Orsat apparatus, Fig. 23, consists of a gas measuring-tube (or burette) and three absorption flasks. A sample of the kiln gas or flue gas having been taken (generally, it is sufficient to take this from the top of kiln), the gas is first con-

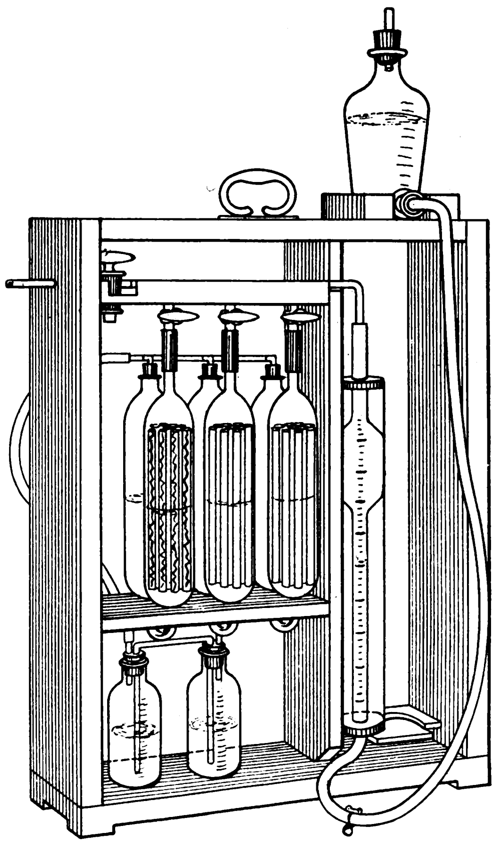


Fig. 23.

ducted into the flask containing a solution of caustic potash, which absorbs the carbonic acid, CO_2. The decrease in volume of the gas, as shown by the measuring tube, is the CO_2. The gas is then admitted to the second flask, containing pyrogallic acid, which absorbs the oxygen. The loss in volume of the gas, shown by the measuring tube, is the oxygen. Next the gas is admitted to the third flask, containing a cuprous chloride solution, which absorbs the carbon monoxide. The decrease in volume of the gas is the CO. The gas that is left remaining in the burette is the nitrogen, which represents seventy-nine per cent. of the air admitted to the kiln, and some water vapor. From these researches, the following conclusions can be drawn:

1. If there is a considerable quantity of CO present, not enough air was admitted to the fuel in the furnaces and the combustion was incomplete.

2. If oxygen is present, and carbonic oxide wanting, the combustion was complete though an excess of air was admitted, which cools down the gases unnecessarily.

3. If, besides an appreciable amount of carbonic oxide, oxygen is also present, it shows either that in consequence of too low a temperature in the furnace there was incomplete combustion, or that there entered later air that took no part in the combustion.

After some practice with this apparatus, such an analysis can be made in about fifteen minutes.

Fuller instructions in regard to the use of the Orsat apparatus, the method of sampling the gas, preparing the solutions, etc., can be found in Lord's Metallurgical Notes and books on gas analysis. A technical man, using large quantities of fuel, would not be satisfied without making tests of the combustion gases, that he can so manage the firing as to prevent waste of fuel.

For general use upon brickyards, Dr. Cramer of the Tonindustrie Zeitung, Berlin, has devised a more simple apparatus based upon the fact that, in most cases, one can tell by the amount of carbonic acid alone, in the kiln or flue gases, whether the firing is being done economically. The carbonic acid in the flue gases bears a direct ratio to the amount of air used. The sum of the carbonic acid and oxygen in the gases, when coke is burned, should always equal twenty-one per cent. As some of the oxygen is used to burn the hydrogen to steam, the perfect combustion of the carbon should yield, with bituminous coal, practically about sixteen per cent. of the volume of the gases. If there is less than this quantity, too much air is being admitted to the kiln. If anthracite coal or coke is used, the percentage of CO_2 should run considerably higher. Under perfect conditions, burning pure carbon, the percentage of CO_2 should be twenty-one.

THE CRAMER APPARATUS.

This apparatus, Fig. 24, consists, essentially, of the flask, A, and the burette, C, graduated to 1-10 per cent. This burette is filled with caustic soda solution. The gas is conducted into the flask by means of the suction bulb, G. For this purpose, it is necessary that the holes in the stopper, B, stand so that the gas can enter the flask. When the flask has been filled, the stopper, B, is turned ninety degrees, whereby

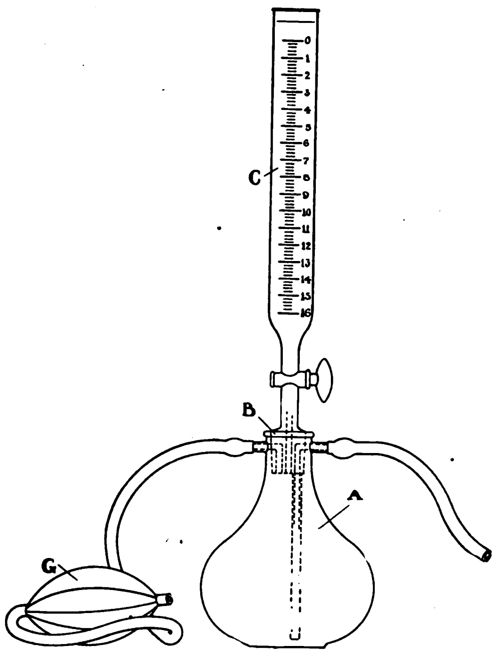


Fig. 24.

the supply of gas is shut off. When the stopcock in the burette is opened, as much caustic soda runs into the flask as there is carbonic acid in the gas, the reading being taken in per cent., directly from the scale.

This is a cheap and thoroughly practical apparatus and should be in use upon every brickyard or other clayworking plant. Used in connection with the draft gage, there could be saved an enormous quantity of coal every year in brickburning.

The character of the combustion is generally expressed by percentage of air used, 100 per cent. being the amount required for perfect combustion. To make this expression from an analysis of gas, with the Orsat apparatus, a simple calculation is made, using the formula, $\frac{N}{N-3.76 \cdot O} \times 100 = \%$ of air under oxidizing conditions, or $\frac{N}{N+3.76 \cdot O} \times 100 = \%$ of air under reducing conditions. In the former case, of course, the percentage is 100 or over; in the latter, the percentage of air is less than 100, and there is incomplete combustion.

The exact percentage of air cannot be obtained from the results of the Cramer apparatus, but it can be approximated closely enough for practical use in brickburning. The calculation is made by solving the proportion 100:21::O:X. O is the amount of oxygen, obtained by subtracting the per cent. of CO_2 from 17. X is the excess of air, which added to 100 gives the percentage of air used. In this case it has been assumed that the fuel is bituminous coal, which generates a maximum of seventeen per cent. of CO_2, the remaining per cent. of oxygen (21—17) going to the combustion of the hydrogen in the coal.

Using Cramer's apparatus, the economy of combustion, or the loss of fuel can be calculated from the percentage of CO_2 in the kiln gases. The calculation is made from Bunte's table. When one cubic foot of CO_2 is formed by combustion of C, 123 calories of heat are evolved. The quantity of heat (=W), calculated from the per cent. of CO_2, is divided by the capacity for heat (=C) of one cubic foot of the chimney gases. The expression, $\frac{W}{C}$, gives the so-called initial temperature.

The larger the per cent. of CO_2, of course, the less the excess of air, and the greater the economy of fuel. Thus, in a hot kiln, with the gases passing out of the brick at a temperature of 1300 degrees F., and the air entering the furnaces at sixty degrees F., if the percentage of CO_2 in the kiln gases is found to be sixteen, which is a perfect condition with bituminous coal, the loss of heat would be twenty-nine per cent. This loss is due entirely to the high temperature of the escaping gases, and is unpreventable in a down-draft kiln, as constructed at present. If the percentage of CO_2 in the kiln gases is found to be eight, which is frequently the case on brick kilns, then the loss of heat, under the same conditions as above, is fifty-four per cent., meaning a loss of fuel, due to excess of air, of twenty-five per cent. A few gas analyses and calculations, as above, will convince anyone of the truth of the statement made in this book, that the waste of fuel in burning brick is enormous.

CONCLUSION.

As was stated in the beginning, the purpose is not to present a general, elaborate treatise upon brickburning, but to give such directions upon the subject of burning brick in downdraft kilns as would enable any manufacturer, using such kilns, to so systemize their operation as not only to obtain a large percentage of first grade brick more economically, but to secure positive, uniform results every time.

The advantages resulting from the use of this system are: (1) Once the proper method of burning any clay or any product has been found, this operation can be repeated indefinitely, thus rendering possible the exact duplication of any desired results. (2) The reproduction of any particular product is no longer locked up in the experience of the brick burners, but becomes a matter of permanent record, which can be consulted at any time.

Whatever may be thought of the manner in which the subject has been presented, all who have had experience in this line should agree that the effort is in the right direction, that only by carrying out such a system of observing and recording, can positive and permanent improvement be made, and the burning of the brick be brought under the control of the manufacturer.

APPENDIX.

TABLES.

One who is making a study of burning brick or other clay wares, frequently has use for information, in condensed form, that will enable him to make calculations, quickly and accurately, in solving the various problems that he encounters. To assist such, as well as to place in convenient form for reference some of the tables pertaining to this subject, that the author has occasion to use in his practice, is the purpose of this appendix.

COMPARISON OF FAHRENHEIT AND CENTIGRADE THERMOMETERS.

In this book the temperatures have been expressed in degrees, Fahrenheit. In scientific treatises, however, in all languages, the Centigrade or Celsius scale is used.

To convert degrees C. to degrees F., multiply by 9, divide by 5 and then add 32. Degrees F. to degrees C., first subtract 32, then multiply by 5 and divide by 9.

TABLE I.

Temperatures. Fahrenheit and Centigrade.

F.	C.	F.	C.	F.	C.
100	37.8	460	237.8	1300	704,4
110	43.3	470	243.3	1325	718.3
120	48.9	480	248.9	1250	732.2
130	54.4	490	254.4	1375	746.1
140	60.	500	260.	1400	760.
150	65.6	525	273.9	1425	773.9
160	71.1	550	287.8	1450	787.8
170	76.7	575	301.7	1475	801.7
180	82.2	600	315.6	1500	815.6
190	87.8	625	329.4	1525	829.5
200	93.3	650	343.3	1550	843.3
210	98.9	675	357.2	1575	857.2
220	104.4	700	371.1	1600	871.1
230	110.	725	385.	1625	885.
240	115.6	750	398.9	1650	898.9
250	121.1	775	412.8	1675	912.8
260	126.7	800	426.7	1700	926.7
270	132.2	825	440.6	1725	940.6
280	137.8	850	454.4	1750	954.4
290	143.3	875	468.3	1775	968.3
300	148.9	900	482.2	1800	982.2
310	154.4	925	496.1	1825	996.1
320	160.	950	510.	1850	1010.
330	165.6	975	524.9	1875	1023.9
340	171.1	1000	537.8	1900	1037.8
350	176.7	1025	551.7	1925	1051.7
360	182.2	1050	565.6	1950	1065.6
370	187.8	1075	579.4	1975	1079.4
380	193.3	1100	593.3	2000	1093.3
390	198.9	1125	607.2	2025	1107.2
400	204.4	1150	621.1	2050	1121.1
410	210.	1175	635.	2075	1135.
420	215.6	1200	648.9	2100	1148.9
430	221.1	1225	662.8	2125	1162.8
440	226.7	1250	676.7	2150	1176.7
450	232.2	1275	690.6	2175	1190.6

TABLE I—Continued.

F.	C.	F.	C.	F.	C.
2200	......1204.4	2475	......1357.2	2750	......1510.
2225	......1218.3	2500	......1371.1	2775	......1523.9
2250	......1232.2	2525	......1385.	2800	......1537.8
2275	......1246.1	2550	......1398.9	2825	......1551.7
2300	......1260.	2575	......1412.8	2850	......1565.6
2325	......1273.9	2600	......1426.7	2875	......1579.4
2350	......1287.8	2625	......1440.6	2900	......1593.3
2375	......1301.7	2650	......1454.4	2925	......1607.2
2400	......1315.6	2675	......1468.3	2950	......1621.1
2425	......1329.4	2700	......1482.2	2975	......1535.
2450	......1343.3	2725	......1496.1	3000	......1649.8

TABLE II.

Weight and Volume of Gases.

Name.	Weight.		Volume.	
	Per Cubic Metre in Kilograms.	Per Cubic Foot in Pounds.	Per Kilogram in Cubic Metres.	Per Pound in Cubic Feet.
Air	1.29318	0.08073	0.773	12.385
Nitrogen	1.25616	0.07845	0.796	12.763
Oxygen	1.4298	0.08926	0.699	11.203
Hydrogen	0.08961	0.00559	11.160	178.83
Carbonic Acid	1.9666	0.12344	0.508	8.147
Carbonic Oxide	1.2515	0.07817	0.800	12.800
Sulphurous Acid ..	2.8605	0.1787	0.349	5.596
Ethylene, C_2H_4	1.2519	0.07814	0.799	12.797
Methane, CH_4	0.7155	0.04466	1.397	22.391

TABLE III.

Relation by Weight and Volume of the Components of Air.

Air contains by volume:

Nitrogen	78.35
Oxygen	20.77
Aqueous vapor	0.84
Carbonic acid	0.04
Total	100.00

Deducting the carbonic acid and aqueous vapor, we have:

Nitrogen, by volume	79.04	By weight	76.83
Oxygen, by volume	20.96	By weight	23.17
Total	100.00		100.00

Ratio of nitrogen to oxygen:

By volume, $\frac{N}{O} = 3.771$ By weight, $\frac{N}{O} = 3.32$

Ratio of air to oxygen:

By volume, $\frac{Air}{O} = 4.771$ By weight, $\frac{Air}{O} = 4.315$

Ratio of air to nitrogen:

By volume, $\frac{Air}{N} = 1.265$ By weight, $\frac{Air}{N} = 1.302$

TABLE IV.

Weight and Volume of Oxygen and Air Necessary for Combustion. (*Ser*).

Combustibles.	Molecular Weights.			Weight per Pound of Combustibles.				Composition by Volume.			Volume in Cubic Feet at 32° per Pound of Combustible.				
				Combustion.								Combustible			
				By Oxygen.		By Air.						By Oxygen.		By Air.	
	Combustible.	Oxygen.	Products.	Oxygen.	Products.	Air.	Products.	Combustible.	Oxygen.	Product.	Gaseous Combustibles.				
				Lbs.	Lbs.	Lbs.	Lbs.	Vol.	Vol.	Vol.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.	Cubic Feet.
Carbon....................	12	32	CO_2 44	2.667	3.667	11.594	12 594	1C	2	$2CO_2$	14.93	29.86	29.86	139.45	139.45
Carbon....................	12	16	CO 28	1.333	2.333	5.797	6.797	1C	1	$2CO$	14.93	14.93	29.86	69.72	84.65
Carb. Ox., CO...........	28	16	CO_2 44	0 571	1.571	2.484	3.484	2CO	1	$2CO_2$	12.79	6.395	12.79	30.74	37.14
Hydrogen	2	16	H_2O 18	8.000	9.000	34.784	35.781	2H	1	$2H_2O$	178.94	89.47	178.94	430.14	519.61
Methane, CH_4........	16	8O=128	{ CO_2 44, H_2O 36 }	4.000	5.000	17.392	18.392	1C, 4H	4	{ $2CO_2$, $4H_2O$ }	22.41	44.82	67.23	215.50	237.91
Ethylene, C_2H_4.....	28	12O=192	{ $2CO_2$ 88, $2H_2O$ 36 }	3.428	4.428	14.903	15.903	1C, 2H	3	{ $2CO_2$, $2H_2O$ }	12.79	38.37	51.16	184.53	197.32

TABLE V.

Quantity of Air Required for Perfect Combustion of Fuels.

Fuel.	Composition.				Air per	
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Kilogram.	Pound.
					Cubic Metres.	Cubic Feet.
Coke	98.0	0.5	....	....	10.09	162.06
Coal, anthracite.	95.4	2.2	1.8	0.5	9.01	144.60
Coal, bituminous	87.0	5.0	4.0	....	8.93	143.40
Lignite	71.0	5.0	19.0	....	7.02	112.43
Peat, dry	58.0	6.0	30.0	....	5.75	92.36
Wood, dry	50.0	6.0	42.0	1.0	4.57	73.36
Petroleum	85.0	14.0	1.0	....	10.76	172.86
Natural gas	.68.7	22.5	1.0	6.2	14.20	227.93
Producer gas ..	1.0	5.0	21.0	69.0	0.72	11.56

UNIT OF HEAT.

The British unit of heat, or British thermal unit, (B. T. U.), is that quantity of heat which is required to raise the temperature of 1 lb. of pure water 1 degree, F., at or near 39.1 degrees, F., the temperature of maximum density of water.

The French thermal unit, or Calorie, which is the unit used by scientists the world over, is that quantity of heat which is required to raise the temperature of 1 kilogram of pure water 1 degree, C., at or about 4 degrees, C.

1 Calorie=3.968 B. T. U.; 1 B. T. U.=0.252 Calories.

TABLE VI.

Specific Heat of Substances.

The specifis heat of a substance is the ratio of the heat required to raise the temperature of a given weight of the substance 1 degree to that required to raise the temperature of the same weight of water 1 degree.

Wrought iron	.1138
Cast iron	.1298
Steel (soft)	.1165
Steel (hard)	.1175
Alumina	.1970
Silicia	.1910
Quartz	.1880
River sand	.195
Brickwork and masonry, about	.20
Stones, generally	.2 to .22
Pine wood	.467
Oak wood	.570
Water	1.0000
Air	.2375
Oxygen	.2175
Hydrogen	3.4090
Nitrogen	.2438
Carbonic acid	.2170
Carbonic oxide	.2479

TABLE VII.

Approximate Weight of One Cord of Different Kinds of Kiln-dried Woods, and Their Evaporate Power Compared With Coal of Average Quality.

Kind of Wood.	Approximate weight of one cord of the wood.	Weight of coal that one cord of wood is approximately equivalent to in evaporative power.
English oak	3,850 lbs.	1,560 lbs.
Ash, beach and thorn, each	3,520 "	1,420 "
Red oak, hard maple and walnut, each	3,310 "	1,340 "
Apple-tree, pear-tree, cherry-tree and plum-tree, each	3,140 "	1,260 "
Birch, elm, plane-tree and hazel, each	2,880 "	1,190 "
Chestnut, brushwood and yellow pine, each	2,520 "	1,130 "
Pitch pine, alder, aspen and poplar, each	2,130 "	1,050 "
Willow, white pine or deal, each	1,920 "	970 "
Hemlock	1,220 "	580 "

TABLE VIII.

Heating Value of Fuels.

	Calories.	B.T.U.
Wood.		
Ash	4711	8480
Beach	4774	8591
Elm	4728	8510
Oak	4620	8316
Pine	5085	9153
Bituminous Coal.		
Alabama, average of 11 tests	7789	14021
Arkansas " " 5 "	7944	14299
Colorado " " 6 "	8060	14516
Illinois " " 68 "	7621	13459
Indiana " " 6 "	7856	14142
Indian Ter. " " 9 "	6875	12219
Iowa " " 4 "	7860	14149
Kansas " " 3 "	6981	12093
Kentucky " " 2 "	8028	14450
Maryland " " 7 "	6386	12998
Mississippi " " 1 "	8204	14768
Missouri " " 8 "	6513	12398
Nebraska " " 1 "	8102	14583
New Mexico " " 1 "	7610	13700
Ohio " " 17 "	8027	14398
Pennsylvania " " 28 "	8280	14904
Tennessee " " 1 "	7315	13167
Texas " " 3 "	6265	11277
Utah " " 1 "	7877	14180
W. Virginia " " 24 "	7801	14041
Wyoming " " 37 "	7451	13412
Nova Scotia " " 3 "	8260	14868
Anthracite Coal.		
Pennsylvania, average of 21 tests	7746	13943
Lignites.		
American, average of 14 tests	6127	10028
Peat.		
Foreign, average of 13 tests	4958	8924
Oven Cokes.		
American, average of 37 tests	8123	14621
Gas Cokes.		
Foreign, average of 14 tests	7918	14352
Petroleum.		
Crude Oil or Residum, average about	11018	19832

TABLE VIII—Continued.

	Per cu. metre	Per cu. foot
Natural Gas.		
American, average of 20 tests............	9259	995
Coal or Illuminating Gas.		
American, average of 15 tests.............	5750	620
Air or Producer Gas.		
American, Anthracite	1274	137
Bituminous	1460	157
Water Gas.		
Average	2994	322

2¼ lbs. of dry wood are equal to 1 lb. average quality of soft coal. The fuel value of the same weight of different woods is nearly the same. Each 10 per cent. of water or moisture in wood detracts about 12 per cent. from its value as fuel.

Petroleum, as fuel oil, has a calorific value about 50 per cent. greater than that of average bituminous coal, weight for weight. A barrel of oil is 42 gallons, weighing about 7½ lbs. to the gallon.

Approximately 30,000 cu. ft. of natural gas have the heating power of 1 ton of coal.

From 1 ton of coal about 130,000 cu. ft. of producer gas can be obtained. Producer gas, or air gas, is the lowest in combustible, both in weight and by volume, of all fuel gases. Next in order of heat energy comes water gas, having for equal volumes more than double the calorific value of air gas. Third in the ascending scale stands coal gas, the ordinary illuminating gas distilled from bituminous coal, which carries more than double the heat energy of water gas. Last and highest in the list of gaseous fuels comes natural gas, which has a calorific value about 50 per cent. greater than that of coal gas.

Bituminous gas has greater calorific energy than anthracite gas.

Though water gas has greater calorific energy than air gas, there is a large loss of energy entailed in its production. Hence, it is not of great industrial importance.

Value of Gas.

To determine the calorific value of natural gases, the American Society of Mechanical Engineers, a few years since, appointed a committee to make a determination of the relative heating values of natural gas and Pittsburg coal. It was found that one pound of coal evaporated nine pounds of water at a temperature of from 60 to 62 degrees, and one pound of gas evaporated 20 to 31 pounds of water under similar conditions. Practically, one pound of gas is equal to two pounds of coal.

If a ton of Youghiogheny cost $2.00, then natural gas, to be equivalent in a commercial sense, is worth from 7½ to 10 cents per 1,000 cubic feet, without taking into consideration the diminution of required labor.

TABLE IX.

Producer Gas From One Ton of Coal.

(W. H. Blauvelt, Trans. A. I. M. E., XVIII, 614.)

Analysis by Vol.	Per Cent.	Cubic Feet.	Lbs.	Equal to
CO.........	25.3	33,213.84	2,451.20	1050.51 lbs. C+1400.7 lbs. O.
H..........	9.2	12,077.76	63.56	63.56 lbs. H.
CH........	3.1	4,069.68	174.66	174.66 lbs. CH_4.
C_2H_4.......	0.8	1,050.24	77.78	77.78 lbs. C_2H_4.
CO_2........	3.4	4,463.52	519.02	141.54 lbs. C+377.44 lbs. O.
N (by diff.).	58.2	76,404.96	5,659.63	7350.17 lbs. air.
	100.00	131,280.00	8,945.85	

Average composition by volume of producer gas; A, made with open grates, no steam in blast; B, open grates, steam-jet in blast. Ten samples of each. (H. H. Campbell, Trans. A. I. M. E.)

	CO_2	O	C_2H_4	CO	H	CH_4	N
A, average......	4.84	0.4	0.34	22.1	6.8	3.74	61.78
B, average......	5.3	0.54	0.36	22.74	8.37	2.56	60.13

The coal used contained carbon, 82%, hydrogen, 4.7%.

TABLE X.

Comparative Costs of Oil and Coal.

Weight of oil per gallon=7.66 pounds. Weight of oil per barrel of 42 U. S. gallons=322 pounds. These figures are net evaporation, after allowing for steam consumed to produce the forced draft necessary for burning the fuel. By "wet coal" is meant coal containing 3% water.	Bituminous Coal Mined West of Ohio and Used in Western and South-western States.	Small Sizes of Anthracite.				Pittsburg Bituminous, Used in Mills of Pennsylvania and on Great Lakes.	Best Semi-Bituminous, Atlantic Ocean Traffic and Mills of Eastern and Middle States.		
		Culm.	No. 3, Buckwheat or Barley.	No. 2, Buckwheat or Rice.	No. 1, Buckwheat and Pea.		Hand Fired.	Mechanical Stokers and Patent Furnaces — Introducing Air Over Fire.	
								Ash 10%.	Ash 5%.
1. Pounds evaporation per lb. of wet coal, from and at 212°, at about 10 sq. ft. of heating surface per boiler horsepower	7.5	7.75_2	8.25_2	8.50_2	8.75	9.50	10.00	10.50	11.00
2. Pounds evaporation per lb. of Beaumont oil, from and at 212°, at about 10 sq. ft. of heating surface per boiler horsepower	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
3. Ratio of evaporation of oil to coal = line 2 ÷ line 1=R	1.97	1.91	1.79	1.74	1.69	1.56	1.48	1.41	1.35
4. Number of barrels of oil equivalent to a 2240 lb. ton of wet coal=2240÷(322 R)=N	3.54	3.64	3.90	4.00	4.12	4.46	4.70	4.94	5.15

EQUIVALENT PRICE OF OIL PER BARREL OF 42 U. S. GALLONS=Pc. ÷ N = Po.

Price of coal per ton of 2240 pounds, Pc.									
$1.00	$0.29	$0.28	$0.26	$0.25	$0.25	$0.23	$0.21	$0.20	$0.19
1.50	0.43	0.41	0.39	0.38	0.36	0.34	0.32	0.30	0.29
2.00	0.56	0.55	0.51	0.50	0.49	0.45	0.43	0.40	0.39
2.50	0.71	0.69	0.64	0.62	0.60	0.56	0.53	0.50	0.49
3.00	0.85	0.82	0.77	0.75	0.73	0.67	0.64	0.60	0.58
3.50	0.99	0.96	0.90	0.87	0.85	0.78	0.75	0.71	0.68
4.00	1.13	1.10	1.02	1.00	0.97	0.90	0.85	0.81	0.77
4.50	1.28	1.23	1.16	1.13	1.09	1.01	0.96	0.91	0.87

TABLE XI.

Bunte's Table.

For calculating the per cent. loss of heat from furnace gases.

Coal=C. 84.45; H. 5.43; O. 8.18; S. 0.75; N. 1.16.

Percentage of CO_2 in the Flue Gases.	Capacity for Heat in Cals. of the Flue Gases=C.		Initial Temperature °C $\left(\frac{W}{C}\right)$		Difference for 0.1 Per Cent of CO_2.
	Per Cu. M.	Per Cu. Ft.	For Carbon.	For Coal.	
1...........	0.308	0.00873	141	167	16
2...........	0.310	0.00877	280	331	16
3...........	0.311	0.00880	419	493	16
4...........	0.312	0.00883	557	652	15
5...........	0.313	0.00886	694	808	15
6...........	0.314	0.00889	830	961	15
7...........	0.315	0.00892	962	1112	15
8...........	0.316	0.00895	1096	1261	15
9...........	0.318	0.00899	1229	1407	14
10..........	0.319	0.00903	1360	1550	14
11..........	0.320	0.00907	1490	1692	14
12..........	0.322	0.00911	1620	1830	14
13..........	0.323	0.00914	1750	1968	13
14..........	0.324	0.00916	1880	2102	13
15..........	0.324	0.00918	2005	2237	13
16..........	0.325	0.00920	2130	2366	..

Example—To find the per cent. loss of heat when the per cent. of CO_2 in the flue gases is 10.

$$\frac{2366-1550}{2366} \times 100 = 34.5\,\%\text{ loss of heat.}$$

(2366 being initial temperature under the best conditions for the above coal.)

TABLE XII.

High Temperatures Judged by Color.

The temperature of a body can be approximately judged by the experienced eye unaided, and M. Pouillet, in 1836, constructed a table, which has been corrected by later investigations of Howe, of White and of Taylor, giving the colors and their corresponding temperature as below:

	Deg. C.	Deg. F.
Lowest red, visible in dark	470	878
Lowest red, visible in daylight	475	887
Dark red, blood red, low red	566	1050
Cherry, full red	746	1375
Light red, light cherry	843	1550
Orange	899	1650
Light Orange	941	1725
Yellow	996	1825
Light yellow	1079	1975
White	1205	2200
Dazzling White heat	1500 to 1600	2732 to 2912

The results, however, are unsatisfactory, as much depends upon the susceptibility of the retina of the observer to light as well as upon the degree of illumination under which the observation is made.

TABLE XIII.

Fusion Points of Seger Cones.

Cone No.	Fusing Point.		Cone No.	Fusing Point.		No. Cone	Fusing Point.	
	F.	C.		F.	C.		F.	C.
022	1,094	590	01	2,066	1,130	20	2,786	1,530
021	1,148	620	1	2,102	1,150	21	2,822	1,550
020	1,202	650	2	2,138	1,170	22	2,858	1,570
019	1,256	680	3	2,174	1,190	23	2,894	1,590
018	1,310	710	4	2,210	1,210	24	2,930	1,610
017	1,364	740	5	2,246	1,230	25	2,966	1,630
016	1,418	770	6	2,282	1,250	26	3,002	1,650
015	1,472	800	7	2,318	1,270	27	3,038	1,670
014	1,526	830	8	2,354	1,290	28	3,074	1,690
013	1,580	860	9	2,390	1,310	29	3,110	1,710
012	1,634	890	10	2,426	1,330	30	3,146	1,730
011	1,688	920	11	2,462	1,350	31	3,182	1,750
010	1,742	950	12	2,498	1,370	32	3,218	1,770
09	1,778	970	13	2,534	1,390	33	3,254	1,790
08	1,814	990	14	2,570	1,410	34	3,290	1,810
07	1,850	1,010	15	2,606	1,430	35	3,326	1,830
06	1,886	1,030	16	2,642	1,450	36	3,362	1,850
05	1,922	1,050	17	2,678	1,470	37	3,398	1,870
04	1,958	1,070	18	2,714	1,490	38	3,434	1,890
03	1,994	1,090	19	2,750	1,510	39	3,470	1,910
02	2,030	1,110						

TABLE XIV.

Melting—Points of Various Substances.

	F.
Sulphur	239
Alloy, 1½ tin, 1 lead	334
Alloy, 1 tin, 1 lead	370 to 466
Tin	442 to 446
Lead	618
Zinc	779
Aluminum	1157
Magnesium	1200
Calcium	Full red heat
Bronze	1692
Silver	1733
Gold	1913
Copper	1929
Cast iron, white	2075
Cast iron, gray	2228
Steel	2372 to 2532
Steel, hard	2570
Mild	2687
Wrought iron	2732 to 2912
Platinum	3227

Cobalt, nickel and manganese, fusible in highest heat of forge. Tungsten and chromium, not fusible in forge, but soften and agglomerate. Platinum and iridium, fusible only before the oxyhydrogen blowpipe.

TABLE XV.

Temperatures in Some Industrial Operations.

(W. C. Roberts-Austen and Prof. Le Chatelier.)

	Degrees. C.	Degrees. F.
Gold Standard alloy pouring into molds........	1,180	2,156
Annealing blanks for coinage, furnace chamber	890	1,634
Silver-Standard alloy pouring into molds......	980	1,796
Steel—Bessemer Process, Six-ton Converter:		
Bath of slag	1,580	2,876
Metal in ladle	1,640	2,984
Metal in ingot mold	1,580	2,876
Ingot in reheating furnace	1,200	2,192
Ingot under hammer	1,080	1,976
Siemen's Open Hearth Furnace:		
Producer gas near gas generator	720	1,328
Producer gas entering recuperator chamber.	400	.752
Producer gas leaving recuperator chamber ..	1,200	2,192
Air issuing from recuperator chamber	1,000	1,832
Products of combustion approaching chimney..	300	590
End of melting pig charge	1,420	2,588
Completion of conversion	1,500	2,732
Pouring steel into ladle, beginning	1,580	2,876
Pouring steel into ladle, ending	1,490	2,714
In the molds	1,520	2,768
Siemen's Crucible Furnace:		
Temperature of hearth between crucibles	1,600	2,912
Blast Furnace or Gray Bessemer:		
Opening in front of tuyere	1,930	3,506
Molten metal, beginning to tap	1,400	2,552
Molten metal, end of tap	1,570	2,858
Siemen's Glass Melting Furnace:		
Temperature of furnace	1,400	2,552
Melted glass	1,310	2,390
Annealing bottles	585	1,085
Furnace for hard porcelain, end of baking......	1,370	2,498
Hoffman red brick kiln, burning temperature....	1,100	2,012

TABLE XVI.

Temperatures Employed in Burning Brick and Clay Wares.

	Cone.	Temperature.	
		F.	C.
Porcelain colors and lusters	022 to 010	1094 to 1742	590 to 950
Common building brick, drain tile, stove tiles and the like, iron and lime-bearing clays	015 to 01	1472 to 2066	800 to 1130
Roofing tile	010 to 1	1742 to 2102	950 to 1150
Art pottery: Biscuit	05 to 1	1922 to 2102	1050 to 1150
Art pottery: Glaze: Glossy	010 to 2	1742 to 2138	950 to 1170
Art pottery: Glaze: Matt	05 to 4	1922 to 2210	1050 to 1210
Sewer pipe from shale	05 to 1	1922 to 2102	1050 to 1150
Common cream brick from limey clays	03 to 2	1994 to 2138	1090 to 1170
Paving brick from shales	1 to 4	2102 to 2210	1150 to 1210
Sewer pipe from fireclay	1 to 8	2102 to 2354	1150 to 1290
Whiteware pottery: Biscuit	3 to 10	2174 to 2426	1190 to 1330
Whiteware pottery: Glaze	010 to 10	1742 to 2426	950 to 1330
Face-brick from fireclays	3 to 10	2174 to 2426	1190 to 1330
Floor tiles: Encaustic	4 to 7	2210 to 2318	1210 to 1270
Floor tiles: Vitreous	7 to 10	2318 to 2426	1270 to 1330
Paving brick from fireclays	4 to 8	2210 to 2354	1210 to 1290
Stoneware, with salt or slip glazes	5 to 10	2246 to 2426	1230 to 1330
Fireproofing	1 to 8	2102 to 2354	1150 to 1290
Fire brick, cement and porcelain	10 to 20	2426 to 2786	1330 to 1530
Glass tank blocks	10 to 20	2426 to 2786	1330 to 1530
Gas retorts	15 to 20	2606 to 2786	1430 to 1530
Silica brick and hard-flowing glazes	20 to 26	2786 to 3002	1530 to 1650

Drying shrinkage of clays ....1% to 10%
Burning shrinkage of clays ....0% to 8%

The resistance of a clay to fusion depends upon (1), the amount of fluxing impurities; (2), the condition of the fluxes; (3), the size of the grains, and (4), the condition of the kiln atmosphere, whether oxidizing or reducing.

A clay is not considered by technicists to be suitable for the manufacture of refractory products that will fuse under cone 26, 3002 F. For the most refractory purposes, such as glass pots and steel crucibles, the clay should not fuse under cone 36, 3362 F.

OXIDIZING AND REDUCING FIRE.

These terms are much used and should be clearly understood by brick burners. The names refer to the action of the hot gases upon the clay, more especially upon the iron of the clay—the oxidizing fire maintaining or producing the higher oxides and the *ferric* compounds, and the reducing fire taking from the iron some of its oxygen, producing the lower oxides and the *ferrous* compounds.

An oxidizing fire is one where an excess of air is admitted to the burning fuel so that the flame is clear and still contains some unused oxygen.

A reducing fire is the opposite of the oxidizing fire, and is burning with a smoky flame and a smaller supply of air.

The color of most clay products is much affected by the manner of the firing during the vitrification period—that is, whether oxidizing or reducing conditions exist in the kiln.

TABLE XVII.

Draft Power of Chimneys.

The following table, quoted from Thomas Box, shows the draft power of chimneys, etc., with the internal air 552 degrees, and the external air 62 degrees, and with the damper nearly closed:

Height of Chimney in Feet.	Draft Power in Millimeters of Water.	Theoretical Velocity in Feet per Second.	
		Cold Air Entering.	Hot Air At Exit.
10	1.854	17.8	35.6
20	3.708	25.3	50.6
30	5.563	31.0	62.0
40	7.417	35.7	71.4
50	9.271	40.0	80.0
60	11.125	43.8	87.6
70	12.979	47.3	94.6
80	14.859	50.6	101.2
90	16.688	53.7	107.4
100	18.542	56.5	113.0
120	22.250	62.0	124.0
150	27.813	69.3	138.6
175	32.436	74.3	149.6
200	37.084	80.0	160.0

TABLE XVIII.

Draft in Chimney at Different Internal Temperatures.

The following table from Thomas Box shows the power of the draft in the chimney at different internal temperatures, of a chimney 80 feet high, 2 feet 9 inches diameter, with a flue 100 feet long from the furnace to the foot of chimney:

Temperature of Air in Chimney.	Draft in Millimeters of Water.	Pounds of Coal per Square Foot Chimney Space.
192 degrees	5.944	120
322 "	9.906	150
452 "	12.700	168
582 "	14.859	180
712 "	16.510	188
1102 "	19.812	195

TABLE XIX.

Rate of Combustion Due to Height of Chimney.

(WM. WALLACE CHRISTIE.)

Diameter, inches.	Area (a) sq. ft.	HEIGHT OF CHIMNEY.														Equivalent square chimney—side of square.
		50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.	225 ft.	250 ft.	300 ft.	
		Pounds of Coal Burned per Hour=13×G.														
18	1.77	169	182	195	208											16
21	2.41	221	247	260	273											19
24	3.14	286	312	338	364	390										22
27	3.98	364	403	429	455	494										24
30	4.91	455	494	533	572	611	637									27
33	5.94		598	650	689	728	767	896								30
36	7.07		715	767	819	871	910	962	1,027							32
39	8.30			897	962	1,027	1,079	1,131	1,209							35
42	9.62			1,053	1,128	1,183	1,248	1,326	1,404	1,560						38
48	12.57				1,456	1,547	1,638	1,716	1,833	2,041						43
54	15.90					1,953	2,067	2,171	2,314	2,587	2,730					48
60	19.64					2,418	2,548	2,678	2,860	3,198	3,380					54
66	23.76						3,094	3,237	3,458	3,861	4,082	4,368				59
72	28.27						3,679	3,848	4,121	4,589	4,859	5,200	5,612			64
78	33.18							4,524	4,823	5,395	5,837	6,097	6,474	6,825		70
84	38.48							5,239	5,603	6,253	6,617	7,072	7,501	7,904	8,658	75
90	44.18								6,435	7,176	7,592	8,125	8,519	9,074	9,945	80
96	50.27								7,319	8,164	8,645	9,213	9,802	10,335	11,823	86
102	56.75								8,268	9,217	9,737	10,426	11,063	11,661	12,779	91
108	63.62								9,256	10,335	10,933	11,700	12,402	13,078	14,313	96
114	70.88									11,518	12,181	13,026	13,819	14,573	15,964	101
120	78.54									12,766	13,494	14,443	15,314	16,146	17,680	107
132	95.03									15,444	16,828	17,472	18,525	19,526	21,398	117
144	118.10									18,382	19,435	20,800	22,061	23,244	25,467	128

TABLE XX.

Effect of the Length of the Flue Leading to Stack Upon the Intensity of the Draft.

The length of the flue leading to the stack changes the intensity of the draft. Thomas Box gives the following table of the power of a chimney 60 feet high, 2 feet 9 inches square, with the flues of different lengths:

Length of Flue in Feet.	Horsepower.	Length of Flue in Feet.	Horsepower.
50	107.6	800	56.1
100	100.0	1,000	51.4
200	85.3	1,500	43.3
400	70.8	2,000	38.2
600	62.5	3,000	31.7

TESTING OF BRICK.

Building brick are tested for crushing strength, transverse strength and absorption. There are no standard tests and specifications for building brick, though the matter is now under consideration by a committee of the American Society for Testing Materials.

Crushing tests of building brick made by Prof. I. A. Woolsen, of the Department of Mechanical Engineering, Columbia University, for the New Jersey Geological Survey, showed as follows:

	Lbs. per Sq. In.		
	Min.	Max.	Aver.
Stiff-Mud Brick.			
Average of 19 different makes of brick—3 to 7 tests of each	4103	6306	5205
Soft-Mud Brick.			
Average of 10 different makes of brick—1 to 6 tests of each	2809	3955	3382
Dry-Pressed Brick.			
Average of 4 different makes of brick—4 tests of each	7749	10364	9056

Transverse tests of the same brick, made by Prof. Woolsen, the rounded knife edge supports being 6 inches apart, and the pressure applied upon the upper side of the brick midway between the supports, gave the following results:

	Modulus of Rupture, in Pounds.		
	Min.	Max.	Aver.
Stiff-Mud Brick	712	1188	950
Soft-Mud Brick	457	666	562
Dry-Pressed Brick	1056	1237	1146

Absorption tests were made on all of the above brick, and upon others, except the dry-pressed, by Dr. Heinrich Ries, of Cornell University. The samples, half brick, were first thoroughly dried, weighed and then soaked in water for forty-eight hours, after which they were weighed again.

Of eight different kinds of soft-mud bricks, the lowest absorption was 5.36 per cent., and the highest 18.64 per cent., the average being 13.39 per cent. Of 14 kinds of stiff-mud bricks, the lowest absorption was 1.34 per cent., and the highest, 14.29 per cent., the average being 10.19 per cent.

The above tests are also sometimes made for paving brick, in connection with the rattler test, but elaborate investigations made by the Committee on Technical Investigation of the National Brick Manufacturers' Association of the United States proved that the Rattler Test is the most reliable and accomplishes all that is desired in determining the wearing qualities of paving brick. The full report of the Committee shows something of the immense amount of work done for the Association by Prof. Edward Orton, Jr., in establishing a standard method of conducting the Rattler Test.

Specification for Conducting the Standard Rattler Test for Paving Brick.

1. DIMENSIONS OF THE MACHINE—The standard machine shall be 28 inches in diameter and 20 inches in length, measured inside the rattling chamber.

Other machines may be used, varying in diameter between 26 and 30 inches and in length from 18 to 24 inches, but if this is done, a record of it must be attached to the official report. Long rattlers must be cut up into sections of suitable length by the insertion of an iron diaphragm at the proper point.

2. CONSTRUCTION OF THE MACHINE—The barrel may be driven by trunions at one or both ends, or by rollers underneath, but in no case shall a shaft pass through the rattler chamber. The cross-section of the barrel shall be a regular polygon, having fourteen sides. The heads shall be composed of gray cast-iron, not chilled or case-hardened. The staves shall preferably be composed of steel plates, as cast-iron peans and ultimately breaks under the wearing action on the inside. There shall be a space of one-fourth on an inch between the staves for the escape of the dust and the small pieces of waste.

Other machines may be used having from twelve to sixteen staves, with openings from one-eigth to three-eighths of an inch between staves, but if this is done, a record of it must be attached to the official report of the test.

3. COMPOSITION OF THE CHARGE—All tests must be executed on charges containing but one make of paving material at a time. The charge shall be composed of the brick to be tested and iron abrasive material. The brick charge shall consist of that number of whole bricks or blocks whose combined volume most nearly amounts to 1,000 cubic inches, or 8 per cent. of the cubic contents of the rattling chamber.

(Nine, ten or eleven are the number required for the ordinary sizes on the market). The abrasive charge shall consist of 300 pounds of shot made of ordinary machinery cast-iron. This shot shall be of two sizes, as described below, and the shot charge shall be composed of one-fourth (75 pounds) of the larger size and three-fourths (225 pounds) of the smaller size.

4. SIZE OF THE SHOT—The larger size shall weigh about seven and one-half pounds and be about two and one-half inches square and four and one-half inches long, with slightly rounded edges. The smaller size shall be one and one-half-inch cubes, weighing about seven-eighths of a pound each, with square corners and edges. The individual shot shall be replaced by new ones when they have lost one-tenth of their original weight.

5. REVOLUTIONS OF THE CHARGE—The number of revolutions of the standard test shall be 1,800, and the speed of rotation shall not fall below 28 nor exceed 30 per minute. The belt power shall be sufficient to rotate the rattler at the same speed whether charged or empty.

6. CONDITION OF THE CHARGE—The bricks composing a charge shall be thoroughly dried before making the tests.

7. THE CALCULATION OF THE RESULTS—The loss shall be calculated in percentages of the weight of the dry brick composing the charge, and no results shall be considered as official unless it is the average of two distinct and complete tests, made on separate charges of brick.

Losses from Standard Rattler Test.

Prof. Orton has made a most thorough study of the testing of paving brick, and in a paper presented to the American Society for Testing Materials, says:

"The losses found in average paving bricks obtained by this process of testing vary from 12 to 25 per cent. Occasionally figures below 10 per cent. have been reported, but they are very rare indeed, and perhaps not fully authenticated. Losses up to 35 and 40 per cent. are common on materials submitted for test as paving bricks, but it is believed that such bricks are not used and are merely tested for information as to their possibilities.

"There is no standard or limit set by the N. B. M. A. as to what constitutes an acceptable loss per cent. in this test.

They rightly leave that question to the engineer who is to use the material to determine. The figures in use in different localities naturally differ with the climate, the size of the town, the intensity of the wear, the size of the loads likely to be hauled, etc. In Columbus, Ohio, the limit set is 18 per cent. loss on abrasion, and no other test is employed. In Chicago, I am informed that the limit has been 17 per cent. at one time, and 15 at another. The latter figure is undoubtedly very severe, and can be met only by a small proportion of manufacturers. In my judgment, 17 per cent. for heavy traffic streets and 20 per cent. for light residence streets constitute reasonable limits, which can be met by the makers of the great majority of the brands on the market, if they use proper care in sorting their product."

Firebrick.

No standard method of testing firebrick has ever been proposed in this country. Very little has been written upon firebrick in English, though there are some good German works, notable Bischof's Die Feuerfesten Tone.

STANDARD SIZES OF BRICK.

The National Brick Manufacturers Association in 1893 adopted as a standard size for common building brick, 8¼ in.x4 in. x 2¼ in., which is still in force, though the sizes vary somewhat, even at the same factory, on account of the variation in shrinkage. A somewhat larger brick is made in the East than in the West, as a rule. The Association also adopted a standard size of the face-brick and of paving brick. The former was not accurate and did not have the endorsement of the face-brick manufacturers, and the latter has become obsolete from the almost universal demand for a special size block for street paving, the exact form and size of which varies in different cities and for different conditions of subsoil, grade and traffic. This matter should, however, receive further attention by brick manufacturers' organizations. No attempt has ever been made to establish standard sizes of firebrick. This is done in Germany and is much needed in this country. Not only should there be a standard size of the square brick, but also standard sizes of arch, wedge, key and other shapes of firebrick. There is much good that could be accomplished by an American association of manufacturers of fireclay products.

STANDARD SIZES OF BUILDING BRICK IN EUROPEAN COUNTRIES.

	Inches.		
	Length.	Width.	Thickness.
German Empire, standard form...	9.8425	4.7244	2.5690
Northwest Germany, small form..	8.6614	4.1338	2.2047
Bavaria, large form..............	11.4173	5.5118	2.3622
Austria	11.4173	5.5118	2.5690
Italy	8.6614	4.3307	1.9685
	9.0651	6.6929	2.7559
France	8.6614	4.3307	2.3622
England	9.8425	4.3307	2.3622
England	9.9999	4.8818	2.9921
Belgium and the Netherlands (Pflasterziegel)	9.4488	4.7244	2.3622
Switzerland	9.8425	4.7244	2.3622
Russia	9.8425	4.7244	2.3622
Russia	11.4173	5.5118	3.1496