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Practical Handling Of
Iowa Clays

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Iowa Clays

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STATION

Practical Handling of Iowa Clays

With

Application of Ceramic Principles

BY

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BULLETIN 43

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CHARACTERISTICS OF IOWA CLAYS AND CLAY WARES.

Principal Clays Utilized in Iowa	Typical Characteristics	Preparation Machinery	Wares for Which Utilized	Manufacturing Characteristics	Characteristics of the Ware
Loess	Sandy, no pebbles, Uniform size of grain, Low plasticity.	Open pug mills, usually.	Common and pressed brick and small drain tile.	Low shrinkage. Poor drying properties.	Color varies from good red to dirty browns. High absorption.
Surface and Glacial Clays	Contains considerable grit, Usually some lime pebbles, Fair plasticity.	Open pug mills and frequently rolls.	Common brick and small drain tile.		Color, commonly red. frequently lime specked.
Coal Measure Shales	Contains some bituminous strata or coaly material, some Pyrite or Marcasite.	Dry and wet pan and pug mills.	Common, face and paving brick, hollow block, drain tile and sewer pipe.	Black cores unless kilns are properly handled. Pyrite causes a rough surface.	Color from fair red to chocolate and almost black. High crushing strength. Rough surface.
Devonian Shales	Smooth ,easily slaked, high lime, some pyrite Good Plasticity	Smooth and disintegrating rolls and open pug mills.	Common brick, hollow block, drain tile and fireproofing.	Laminates badly. Low fuel cost at the kiln.	Color, salmon-red to chocolate brown when flashed.
Cretaceous Shales	Very siliceous, fair plasticity.	Dry pans and open pug mills.	Common and face brick, hollow block and drain tile.	Low shrinkage. Requires rather a high heat to reduce to low absorption.	Color, buff to dark red.

I. THE PROSPECTING AND TESTING OF CLAYS FOR THE MANUFACTURE OF CRUDE PRODUCTS.

HOMER F. STALEY.

INTRODUCTION.

The manufacture of clay products is a very poor business for a beginner. While this statement is true of any business, it applies with particular force to the manufacture of crude clay products. In most any other business, operations can be started on a small scale and methods and equipment altered as the business grows. Even a change of location is not unusual. On the other hand, in the manufacture of crude clay products, a definite location must be secured and a complete plant built before operations can be carried on at a profit. If a mistake is made in locating the plant, it can not be moved and is of little value for any other use. If poor judgment is used in installing a certain type of machinery, dryer, or kilns, the error can be corrected only at great expense. In fact, from an economic standpoint the decisions that must be made in locating and building a clay plant are irrevocable.

In spite of the great hazard in the location and building of brick and tile plants, there seems to be a general idea among small investors that such a plant can be built wherever there is an outcrop of clay, and be made to pay. The consequence is that the loss due to ignorant and ill-advised investments is enormous. In this State alone, several plants, costing up into the thousands of dollars, have been built at points where there is no clay of suitable quality. Such a gross mistake is hardly conceivable.

Other common errors are location of plant where the clay is practically inaccessible, the cost of digging being too great; or where the facilities for manufacture are unfavorable; or the market inadequate or remote. The plant may be built to use a method for which the clay is not suited, or the machinery, dryer or kilns may be of a type not adapted to the conditions existing at the given plant.

Unfortunately most of these losses have fallen on comparatively small investors. Large financiers seldom lose money in this way, simply because they refuse to invest in any enterprise until it has undergone a thorough investigation by the best talent available. But the small investor is liable to be persuaded by the enthusiastic statements of a professional promoter, or to take the equally dangerous, but more disinterested, advice of local ''boosters''. Since, to an outsider, the manufacture of brick and tile looks so simple, this class of investors do not realize the danger, and consequently are liable to think that to

have the proposition investigated by a properly qualified engineer is a needless expense. Of course, some investigation is always made before a new plant is built, but past experience has shown that in by far too many cases the preliminary study of the situation was woefully inadequate.

It is not intended to imply that all brick and tile plants are poor investments, but to insist that all such enterprises should be thoroughly studied by a competent and disinterested investigator. When this is done and the report is favorable, the investor can feel that the business is starting under favorable auspices and that with reasonably efficient management it is assured of success. When once well established under favorable conditions and good management, a factory making crude clay products is fairly certain to pay a moderate dividend for a long term of years on the capital actually invested. It is the main purpose of this paper to indicate what is entailed in the proper investigation of a clay bed.

VALUE OF ENGINEERING SERVICE.

The location and building of a clay products plant calls for the services of a high grade ceramic engineer. The comparatively small expense will be repaid many times by the increased efficiency of the plant, and the investors will be assured against the gross mistakes in judgment that occur too frequently when this plan is not followed. While the advice of the "practical clayworker" should not be disparaged, yet clays and conditions differ so widely that his experience may not have covered a similar situation. An experienced ceramic engineer has a wider knowledge of clays and clayworking problems in general than it is possible for a practical man to have, and also has more effective methods of testing clays and solving manufacturing problems.

LOCATING THE DEPOSITS.

In looking for a suitable clay in a certain locality, all the reports of the State and U. S. Geological Surveys dealing with the clays in the given region should be consulted. By the aid of these, an experienced prospector will be able to identify the various outcrops appearing in natural and artificial excavations such as gullies, stream banks, quarries, railroad cuts, etc. Starting from these, he is usually able, by applying a knowledge of geology, to locate the available clay beds of the region.

PRELIMINARY SAMPLING.

From the most promising location, samples for test should be taken. In taking samples it should always be remembered that the tests will be made on the sample, and the report of

these tests will only apply to that part of the clay bed of which the sample is a fair representative. Therefore, great care should be taken to get representative samples of each portion of the bed, and careful note should be made of the relative abundance of these portions. For instance, if a clay bed consists of several layers occurring both in outcrop and covered positions, samples should be taken of each layer both in the exposed and covered bed. Note should be made of the relative amounts of each of these portions in the bed as a whole. Great care should be employed to include a proper proportion of obvious impurities such as stones, concretions, gypsum crystals, etc. If the bed contains a layer of unusable or objectionable material, careful note should be made of its character, thickness and place of occurrence. If there is any question of its composition, a sample should be taken for analysis.

A simple way to secure a sample of a given layer is to clear a vertical section and then to dig out a uniform furrow from top to bottom, catching the material on a cloth. The furrow should be of such a size as to produce at least a hundred pounds of sample, which should be put into a clean, tight container (not a dirty cement sack or old lime, salt or oil barrel), and carefully labeled.

The samples of clay should be shipped to some ceramic engineering testing laboratory, which must be under the control of competent and wholly disinterested parties. It is stipulated that the testing should be done by wholly disinterested parties, not because it is thought that interested persons would be intentionally dishonest, but because it has been a proverb for thousands of years that it is easy for humans to believe that which it is to their interest to believe.

The people who are to do the testing should be supplied with all available data as to the mode of occurrence, relative amounts, etc., of the various kinds of clays submitted. This information enables the investigators to blend the clay samples in the various proportions in which it would be possible to dig them from the bank.

PRELIMINARY TESTS.

The tests made on each clay and mixture of clays should cover at least the following points:

I. General character of the raw clay
   (a) Color
   (b) Structure
   (c) Fineness of grain
   (d) Visible objectionable materials
   (e) Presence of carbonates as indicated by acid test.

II. Working properties
    (a) Ease of grinding
    (b) Grade of plasticity
    (c) Tendency to laminate
    (d) Die troubles
III. Drying properties
    (a) Rapidity of drying
    (b) Shrinkage
    (c) Cracking and warping
    (d) Tendency to scum
IV. Burning properties
    (a) Ease of oxidation
    (b) Porosity at cones 07, 04, 02, 1, 3, 5 and 7
    (c) Hardness at same heat treatments
    (d) Shrinkage at same heat treatments
    (e) Color at same heat treatments
    (f) Behavior when overfired
V. Refractoriness (for fire clays only)
    (a) Fusion point
    (b) Load test at high temperatures

CHEMICAL ANALYSIS.

Chemical analyses are not desirable as a preliminary test for clays to be used for crude products. The clays used for such purposes vary so widely in composition and the relations between compositions and physical properties are so obscure that, in general, chemical analyses are of little value in judging the value of the clay. If, in the preliminary or more complete tests, the most available clay develops some defect, the explanation or cure for which seems liable to be discoverable by means of a chemical analysis, either a complete or partial analysis should be made. Complete chemical analyses may also be used in conjunction with practical tests to determine the uniformity of a clay bed at different points.

EXTENDED TESTS.

The preliminary tests will show in a general way the possibilities of the various clay beds sampled. If the tests are satisfactory for a clay from a bed that seems available from the standpoint of location, amount of material probably present, etc , more extended tests of this clay should be made. These tests should approach as nearly as possible to manufacture under commercial conditions according to the processes that the preliminary tests indicated were most suitable for the particular clay or mixture of clays. It will seldom happen that this work can be carried on in a commercial plant, since the conditions at a given plant are not liable to be ideal for the working of the new clay.

Moreover, a small amount of ware made from one clay and dried and burned with a large amount from another clay may not give the same results that a large amount of ware from the first clay would have given.

As illustrations of the danger of ''practical testing'' of clay may be cited two instances, which are typical of many others. Some parties wishing to make sewer pipe from a shale, which in its general physical properties was suitable for that class of ware, had a number of pieces made up and burned in a neighboring sewer pipe plant. The trials were satisfactory in every respect, and so a large plant was built. However, when the first kilns at the new plant were fired, the ware in the kilns caught on fire as soon as red heat was reached and melted to a lot of warped and bloated clinkers. On examination, it was found that the clay contained several per cent of bituminous material which was given off as an inflamable gas at red heat The small amount of gas from the few pieces had no appreciable effect on the large kiln in which almost all of the ware was made from non-bituminous shale. When, however an attempt was made to burn the kilns filled entirely with ware made from the bituminous shale, the large amount of combustible gases given off took fire and raised the heat so rapidly that the ware was ruined. Since they had their money invested, these people had to make ware in the best way possible, and therefore, devised a slow and expensive way of burning so as to avoid, as far as possible, the ill effects of the bituminous matter in their clay. The plant never paid, changed hands several times, was converted into a brick plant, which also failed, owing to the difficulty of burning the clay, and finally, before it was half worn out, was abandoned.

Another man wished to make dry press face brick and to burn them in a continuous kiln. He made up about a hundred brick at a dry press factory, hauled them to another factory and had them burned in a continuous kiln, along with the general run of well dried stiff mud brick being made there. His samples were very pleasing indeed, being of an especially clear red color. He bought an expensive plot of ground, built a large dry press brick factory, and installed a first-class continuous kiln. All the ware ever made in that plant was scummed. The clay contained a lot of sulfur, which when the trial bricks were fired was simply driven off and deposited on the other man's ware. When the entire continuous kiln at the new plant was filled with sulphur bearing clay, the sulphur was driven out of one lot of the bricks and, mixing with the moisture from the dry press brick, was deposited on the brick farther along in the cool part of the kiln, forming a dense scum. This man worried

along for twenty years selling his product for common brick, finally gave up in despair, tore down his plant and quit the business.

The extended tests, therefore, should be made under the direction of a disinterested and experienced engineer either in a factory or in a testing laboratory. All the points noted in a preliminary test should be studied in more detail, and, in addition, all other peculiarities which the clay develops in manufacture should be carefully considered. Suitable tests should be made to determine the quality of the burned ware. If the tests indicate that some variation in the method of manufacture from that tried would be more suitable, this should not be taken for granted, but a new series of tests should be run. As indicated before, a chemical analysis may be desirable at this time to clear up some debatable point. From these extended tests an experienced ceramic engineer will be able to state definitely the quality of ware that can be made from the clay sample submitted, and to prescribe the most suitable processes of manufacture.

COMPLETE SURVEY AND SAMPLING.

Of course, before the extended tests are made on any clay, the prospectors should be reasonably sure that they have an adequate and available supply of the clay. This, like everything else in a preliminary examination, must be definitely determined. After a clay that proves satisfactory in extended tests is found, a tract of suitable size must be surveyed and systematically sampled. A topographical survey of the tract should be made. Drill holes should be put down 50 feet apart in thick beds and 100 feet apart in thinner deposits, and a record kept of the thickness of each stratum encountered. In addition, samples of the layer or layers of clay which it is expected to work should be set aside for test. A few larger holes should be dug at the extremities of the property in order to get more satisfactory samples. The samples of the clay would then be subjected to the tests described under preliminary tests in order to determine the variation in properties of the clay beds at different points in the tract. If desired, these tests could be supplemented by chemical analyses or other forms of test.

From the results of the survey, maps should be drawn which will show the lay of the land, the extent of the clay beds, their quality at different points, the amount and character of overburden and other extraneous material that will have to be removed in winning the clay, and finally the drainage facilities. From these data an experienced engineer can go about the building of a clay manufacturing plant with the same methodical operations that an experienced highway engineer employs

in building a bridge, and with equal assurance of success. Methodical testing and surveying of a clay property removes the development of the property from the realm of pure chance and makes it a comparatively simple engineering problem.

USES OF THE DATA OBTAINED.

By use of the data supplied by the tests and surveys, the ceramic engineer is able to solve all of what we may call the engineering problems involved in the development of the clay deposit. These problems are listed below by numbers and the data on which their solution depends by letters.

1. Amount of clay of suitable quality present
    (a) Average depth of the layer of suitable quality
    (b) Extent of the layer
    (c) Weight per cubic foot
2. Method and cost of digging the clay
    (a) Physical character and depth of the clay or clays
    (b) Amount and character of the overburden
    (c) Amount and characters of layers or nodules of material that must be removed from the clay in digging.
    (d) Available methods of draining the pit
3. The most economical location on the tract for the plant
    (a) Suitable sites for the plant
    (b) Estimated cost of transporting clay to the plant
    (c) Estimated cost of railroad switches to the plant
4. The kinds of ware that can be made and type of machinery, dryer and kilns to be used
    (a) The physical and burning properties of the clay.

In drawing conclusions from the data presented by the survey, the ceramic engineer makes use of a fund of knowledge derived from his technical training and practical experience. There will be pointed out only a few of the gross errors that might have been avoided by the use of ordinary common sense if such data had been available when certain plants were built.

AMOUNT OF CLAY.

The amount of clay of suitable quality in a given area is found, of course, by multiplying together the depth in feet, area in feet, and weight per cubic foot. Knowing the capacity of the proposed plant, the amount of clay needed for the life of the plant can be estimated. From these figures it can at once be perceived whether the plot under consideration contains enough clay. A child of twelve can make the calculations, yet year after year plants are built in this country on sites which do not contain enough clay. This does not mean that the men who built

these plants are fools. except in the sense that a man is foolish who risks large sums on an uncertainty that could be made certain at a slight expense. They simply assume that the clay examined in two or three places extends over a large area.

In purchasing clay land, it should always be remembered that the capacity of the plant may be increased and that in all probability adjoining land will never be any cheaper. In fact, the establishment of a successful plant automatically raises the value of surrounding land. Since a clay plant cannot be moved without great expense, it is, therefore, generally wise to purchase considerably more clay land than the amount needed to supply the plant at its initial capacity, so as to escape the necessity of buying adjoining beds at high values.

METHOD AND COST OF DIGGING.

The question of digging the clay should be considered as a long-time proposition. It is not a question of how cheap the most accessible clay can be dug for the first few years supply, but a question of how much it is going to cost to dig the total amount of clay needed during the life of the plant. If this had always been done, we would not see the many instances of plants abandoned or working at a serious disadvantage because it becomes more expensive to dig the clay each year. Of course there is no objection to digging the cheapest clay first; but if this is done, the money saved must not be considered as profits and disbursed as dividends or thrown away in cutting prices, but should be set aside as a sinking fund to meet the excessive cost of digging clay in later years.

When it is realized that in the life of only a moderate sized clay plant one to two million tons of clay will be dug, it is plain that a saving of a small amount per ton in the cost of digging will amount to a large sum. Ten cents a ton on a million tons means, of course, $100,000, a sum that may mean the difference between a satisfactory and unsatisfactory investment. Such a saving could in many cases be secured by the use of a proper method of digging in place of an improper method. In other cases, the use of economical systems of digging are precluded by some characteristic of the bank that was unknown or not appreciated at the time the plant was built. In some plants clay is still dug by hand at a cost of 15 cents a ton when it could be dug by machinery at a cost of 5 cents a ton. On the other hand, it is not uncommon to see expensive machinery installed in pits where it is of little value owing to the fact that the pit is not capable of being worked to advantage by that particular kind of machinery. The conditions at each clay pit must be made a subject for special study by a disinterested expert.

As a general proposition, digging by machinery is more economical than by methods calling for a large amount of manual labor. Thin layers of clay are generally expensive to dig because the most effective types of clay digging machinery are not well adapted to such beds. The expense of digging clay with a steam shovel decreases until the thickness of the bed equals the height of cut that can be made by the shovel, 18 to 24 feet. Beyond this height the expense remains about the same, whether the clay is taken out in two cuts or, as is usual, the overhanging clay is blasted down into the pit. With machines of the shale-planer type the expense decreases until a much greater height is reached, since these are essentially machines for deep-cut work.

The amount of overburden must always be considered as relative to the amount of clay beneath it. Twenty feet of burden over fifty feet of clay is in the same ratio as four feet of burden over ten feet of clay. In fact, the twenty feet of burden could be removed more cheaply per cubic yard than the four feet. The amount of overburden that can be removed per ton of clay depends altogether on the value of the clay and the total cost, per ton of good clay, of removing burden and digging the clay. This will depend on local conditions. Eighteen cents a ton would probably be a maximum price for brick and tile clays in Iowa.

The character of the overburden should be carefully considered. Rock will cost six to ten times as much per cubic foot to remove as earth. A layer of hard rock a few inches thick will cost practically as much as if it were a foot thick. Rock in the body of the overburden is more objectionable than if it were at the top or bottom only, since it precludes the effective use of machinery in removing the earthy part of the burden. When the burden contains objectionable material such as limestone pebbles or gypsum concretions, there is a tendency for these to become mixed with the upper layer of the good clay, and it may be necessary to waste part of this.

Layers or nodules of objectionable material in a clay bed always increase the cost of digging. In nearly all cases they preclude the effective use of machinery and in addition cause expense for their own removal. In fact, there is now no known method of removing any considerable amount of nodules of material from a clay for crude wares in an economical manner. Large amounts of money have been lost by confiding investors in the development of this kind of beds. In sending samples for testing, a certain class of promoters are always careful to exclude all such objectionable materials. The result is that a satisfactory report may be made on the clay, while if a proper

proportion of the objectionable material is included the report might be entirely unsatisfactory. In other cases where the harmful substance occurs in layers, operations are begun by digging the clay by hand, and thus the removal of the layers does not increase the expense to a large extent. It is only when the operators wish to change from extravagant hand digging to economical machine digging, that they realize they are forever prevented from doing this by the seemingly trivial layer of objectionable material.

Whenever a clay pit lies below ground-water level, drainage is a continuous expense. The chief difficulty, however, is that the clay retains a large amount of water, no difference what kind of drainage system is installed, and is liable to be too wet to work properly in grinding and screening machinery. Other things being equal, a pit with natural drainage facilities should be chosen.

LOCATION OF PLANT.

There are generally several suitable sites for a plant on any given tract of clay land. The question generally narrows down to a calculation of whether it is cheaper to transport raw clay a considerable distance, or to build longer railroad switches. Local conditions must be taken into consideration, but in general it is cheaper to place the plant close to the clay. Railroad switches entail a larger initial investment, but cost very little for operation and maintenance. A clay transportation system of equal length will cost much less to build, but will be a constant source of large expense for maintenance and operation.

The value of a preliminary survey is often strikingly illustrated in the matter of plant location. The following are only two instances of a number in Iowa. A large brick and tile plant was built in one corner of a tract of clay land. When the plant was practically completed, it was found that the clay at that point was covered by a heavy burden containing a thick layer of hard rock. The plant was torn down piece-meal and rebuilt on the far corner of the tract where the overburden was quite light and contained no rock. Switching facilities were equally good at the two sites. In the other case, the plant was located about a quarter of a mile from the railroad switch and separated from it by a deep gully which precludes the building of a switch. The same clay is found across the gully and adjacent to the railroad.

KIND OF WARE.

The kind of ware to be made and the type of machinery, dryer and kilns to be used should depend upon the physical and burning properties of the clay. Unfortunately, when the test-

ing of the clay and building of the plant is not done under the direction of a disinterested expert, they are made to depend on many irrelevant things.

The samples for testing may have been improperly taken. A small sample of fire clay from a deposit in this state was sent away for test. Word came back that the clay was equal in quality to any in the world. This was probably true; but after the plant was built, it was found that the bed contained a layer of this material just six inches thick. The rest of the deposit was of poor grade. In fact there are several "fire brick" plants in this and adjoining states, whose only trouble is that they have no fire brick clay. The ill effects of failure to incorporate in the sample a just proportion of injurious materials occurring in the bank, the effects of improper methods of testing, and failure to determine the uniformity and extent of the clay bed, have been discussed above.

When it comes to building the plant, every one who has something to sell, be it machinery, a patent dryer, or patent kiln, takes a hand in the game. He is perfectly willing to test the clay free of charge, and the tests generally demonstrate that the clay is peculiarly adapted to the use of his equipment. Choosing from the mass of conflicting advice that pours in from every side, the builders finally erect and equip a plant that, according to the law of averages, is pretty sure to be wrong in one or more important points.

ECONOMIC PROBLEMS.

In addition to the engineering problems, there are several financial considerations that are directly connected with the location of a plant on a particular clay bed. These are:—

1. Investment and other fixed charges
   - (a) Cost of land
   - (b) Cost of particular kind of plant necessary to work the clay successfully
   - (c) Amount of working capital required by method of manufacture and type of market
   - (d) Taxes, insurance, administration, etc.
2. Labor market
   - (a) Supply and type of labor available
   - (b) Cost of labor
3. Supplies
   - (a) Type, quality, and cost of fuel available
   - (b) Same for minor supplies
4. Market
   - (a) Demand for product at a price above cost
   - (b) Cost of selling

(c) Cost of delivering

(d) Competition, existing and possible

These subjects are so much a matter of local conditions that it is not possible to discuss them to advantage in a general treatise. Moreover, they are the sort of questions that any successful business man can understand and are thus of a different order from the highly technical problems involved in testing the clay and building a plant.

Attention should be called to the fact that there has not been listed among the business propositions to be considered in building a plant, the one that is often most powerful,—namely, ease of raising money. Promoters, and sometimes legitimate clayworkers, are often influenced to build a clay working plant in a certain locality, not because it offers an extremely desirable location, but because capital for the new enterprise can be easily raised there. Local pride in a town or community is often an impelling cause to these unwise investments. The development of every clay bed should be made to stand on its own merit. If it is a good proposition from the technical and economic standpoints, capital will be forthcoming, no difference where it is located. If it is not a good proposition from these standpoints, the clay had better be left undeveloped.

Note

The three papers relating to the "Practical Handling of Iowa Clays" were prepared in response to numerous inquiries for information on the subject. The papers were presented informally at the 1915 meeting of the Iowa Clay Manufacturers' Association and were so favorably received that their publication seemed warranted. The writers do not claim any considerable amount of original material. The papers are rather the assembling of all the available material concerning the properties of Iowa Clays and the application of well established ceramic principles thereto. The writings of the leading ceramists have been consulted freely. Wherever literal quotations are made, specific acknowledgments are given in the text. The writers specially desire to acknowledge their indebtedness to the splendid papers of Dean Edward Orton, Jr., and Dr. A. V. Bleininger, and to the epoch making work along ceramic lines of Dr. Herman Seger.

II. MANUFACTURE OF CLAY WARES WITH REFERENCE TO IOWA CONDITIONS.

MILTON F. BEECHER.

INTRODUCTION.

A detailed discussion of the processes involved in the manufacture of clay goods would require volumes; and while it would all be of interest to clay workers, the space available necessitates limiting the discussion to some of the more important features of the methods used in Iowa. While the State ranks eighth in the production of clay goods, the diversity of our lines of endeavor are rather restricted. The bulk of our product is drain tile, in the production of which we rank first among the states, making almost half again as much as the next largest producer. But almost the whole of our production comes within the class of the coarser ceramic wares. The only exception is our limited output of stoneware and roofing tile. The method of manufacture, then, in this State is limited almost wholly to stiff-mud, with considerable variation, of course, in the methods of preparing the clay and drying the ware.

PREPARATION OF CLAYS.

Clay as it comes from the bank is not in condition for shaping for the reason that it contains too little water to be moldable and very rarely even approaches a uniform composition or quality. Reduction of the lump clay is therefore necessary to facilitate the ready assimilation of water and to bring about a more thorough mixing. The means used for reducing is governed by the character of the clay and the product to be made.

GENERAL TYPES OF CLAYS IN IOWA.

In Iowa we have, in general, five kinds of clays from which the great bulk of our product is made; the loess, the glacial and surface clays, the Coal Measures shales, the Devonian shales and the Cretaceous shales.

The **loess,** which covers more than one-half the surface of the State, has peculiarities of shortness, uniform size of grain, and tenderness in drying which render it distinct from other clays and make it easy to identify. This type is being used to a less extent in the past few years, probably because we are passing into an era of larger and fewer factories with consequent discontinuance or assimilition of the smaller plants. This change in Iowa, has affected those plants using the loess and the surface clays. Probably, also the quality of ware possible to produce has been one of the determining factors, for loess and surface

clay products are not usually of a quality equal to shale products.

For these reasons it is not the policy of our Ceramic Department to recommend a loess clay deposit as a feasible proposition for the development of a new plant in Iowa. except with limitations.

The loess clays because of their friable, sandy character are very easily disintegrated. As they come from the bank they are probably more uniform than any other and take up water much more readily. They require the least work in pugging and preparation of any of the Iowa clays.

The **glacial and surface clays,** which may be grouped with the loess, require but little more expenditure of energy in preparation. They differ, however, in having a greater plasticity, usually also containing pebbles of varying sizes. The preparation of these frequently requires the removal of the larger pebbles. Especially is this necessary if the pebbles are of lime; otherwise crushing may be resorted to, to reduce them to permissible size.

The materials requiring the next greater degree of preparation are the **Devonian shales**. These are available only over a limited area of the State. Of most importance are the deposits in Cerro Gordo, Floyd and Franklin Counties where they are very extensively utilized for hollow goods. They slake very readily in water, contain some nodules of iron pyrite, and though the chemical analysis shows quite a large lime content it is not present in the form of pebbles. Ledges of sand rock occur in most of the pits now worked, and while portions of the rock frequently contaminate the clay these may be removed with conical rolls; or if the amount is not too great, they may be crushed and passed on with the clay. The machinery best adapted to preparing this type of clay seems to be smooth or disintegrating rolls and the horizontal pug mill.

The **Coal Measure shales** occur over nearly one-third of the State's extent. The outcrops and workings are confined quite largely to the valley of the Des Moines River and its tributaries. They supply a great abundance of material that is utilized for a great variety of wares and are the most extensively used of any of the Iowa clays.

The **Cretaceous shales** occur in the west and northwest portions of the State. While cretaceous rocks cover quite a large area, the outcrop of usable clays and shales of this geological period are less frequent and are utilized in only a few localities, principal among which is Woodbury County.

The Coal Measures and Cretaceous shales as far as manner of occurrence is concerned, are so much alike as to require prac-

tically the same method of treatment. These pits or mines usually contain strata of both hard and soft clay, and frequently streaks of bituminous, or coaly material. In the case of Coal Measures shales pyritiferous strata are hardly ever absent. Obviously the preparation of these for shaping in the plastic state, requires more thorough and extensive crushing and mixing than the clays mentioned above. The presence of the harder clays and the pyrite-bearing strata make necessary the use of heavy crushing machinery. Dry pans are commonly employed for the purpose.

GRINDING AND TEMPERING MACHINERY.

The simplest machine, and also the one which disintegrates and mixes the clay the least, is the horizontal pug mill. Only such clays as are naturally soft, such as the loess, the glacial and the surface clays, can be sufficiently reduced and tempered in the horizontal pug mill alone, and then only when they do not contain concretions or pebbles that must be crushed or removed. The pug mill is in no sense a crushing machine but simply a mixer, and nothing, of course, is ever accomplished with hard or stony clays in the pug mill. The power consumption of pug mills for a given output is not affected directly by the shape or set of the knives as is often stated, but by the amount of pugging done. The shape and set of the knives affect the amount of pugging and that, in turn, affects the power consumption on the output basis.

For shales and clays of moderate hardness, such as are represented as a class by our Devonion shales, combinations of open pugs and rolls seem sufficient preparation; and for the Coal Measures, and Cretaceous shales, dry and wet pans are almost invariably used.

The amount of preparation that it is feasible to give depends largely upon the kind and quality of ware it is possible to make from any particular clay, for there are few clays that cannot be worked, shaped, dried and burned into serviceable products if the proper methods and precautions are used. However, the market price of any particular kind or quality of ware determines to what extent the proper methods and precautions necessary to the production of a serviceable ware may be carried out, and if a satisfactory average between cost of production and quality cannot be found, the clay is commercially valueless. For instance, certain surface and glacial clays would be usable if the lime pebbles were removed, and the sticky joint clays if preheated properly, or if subjected to the right drying conditions, would dry safely; but the market prices of the resulting product determine whether or not this additional expense may be incurred. With practically all clays, the more

thorough the grinding and pugging, the better the quality of the product; but all wares will not stand the cost of the most thorough preparation possible, nor is it necessary in order to produce a marketable product. When we consider that the power consumption for grinding alone, when dry pans are used, is about one-half the power required for the whole machinery equipment, we see the bearing of the cost of preparation upon the cost of the finished product. (R. R. Hice. Vol. 14. Trans. A. C. S.)

Of the several types of grinding machines in common use, the dry pan seems to be the most efficient as a rough and ready machine, but it is the most wasteful of power. It reduces even the hardest lumps in the clay very effectively, but, because of the large amount of power it consumes, it is commercially adapted only to those clays which are very hard or contain very hard lumps. The wet pan as well, which is very similar in construction and operation, does the best job of tempering; but it also requires a great deal of power, more than half the power delivered to it being required to turn the machine alone, without load. One case may be cited in which a chaser mill, requiring twenty-four horse power under load, took eighteen horse power under no load. The wet pan, however, as originally designed and used was intended to grind and temper the clay directly from the bank; but since the wet pan must operate periodically and the batch must necessarily be small, very little mixture is accomplished, and good uniformity of the clay delivered to the auger machine cannot be obtained. So where wet pans are used today there is usually auxilliary crushing machinery to give proper homogeneity to the clay.

The amount of water necessary to add to the raw clay to give it the proper consistancy for the auger machine varies with different clays; and for each clay that proper amount of water should be determined and used, for much in subsequent operations and in the quality of the ware depends upon the temper of the clay. In common practice the proper working temper is that at which the clay is fluid enough to take almost any shape under reasonable pressure, solid enough to resist change of form due to its own weight, and cohesive as to itself but no longer sticking to the hand or metal surfaces.

FORMATION OF CLAY WARES

All commercial clay wares are formed from the plastic clay under pressure in molds. The diversity in the size and shape of the mold, the variation in the amount of pressure and the degree of plasticity vary greatly. As to the molds, we have on the one hand the closed pressers mold of the potter which imparts to the clay every detail of the desired shape, and on the

other hand the open mold or die of the brickmaker which forms a continuous shape having only two of the desired dimensions. The pressure used varies from almost nothing in the case of pottery casting to the enormous pressures used in dust pressing, the process by which such goods as quarries, tiles and electrical goods are made, and the plasticity from almost nothing in the case of dust pressing to fluidity as in the case of the casting process. The stiff mud process presents about a mean between these limits of pressure and plasticity (if plasticity is broadly understood to mean moldability.)

THE AUGER MACHINE

The principle of the auger machine, the development of which has been the development of the stiff mud process, is simply the continuous application of pressure to a moving clay column. The pressure is primarily applied in only one direction; but plastic clay being neither solid nor fluid, but acting to a certain degree like both, we have the effect of pressure in every direction save one, and consequently a flow in that direction. While there is but one primary application of pressure, the barrel of the machine, frequently the muzzle and always the die, have a certain taper which indirectly applies pressure laterally to the bar and causes a greater compactness.

While auger machines are of several types and many makes, the principle of all is practically the same—the movement of the clay against a certain resistance by means of a screw. The screws may be simple, double or even triple, and may be either continuous or segmental.

The success of the auger machine and the extent to which it is used, is due to its large capacity and its labor saving over the old soft mud and plunger methods of brick making; but it gives to the products defects which are unknown in brick made by the older methods. It requires a stiffer clay, since the brick must bear handling at once, which means a temper at which the clay will heal less readily. Considering the simple auger, we have there a bar of clay formed by compressing a ribbon laid down in a spiral. This ribbon is not only so stiff that it is not sticky, and so heals only imperfectly, but it has been sliding over two or three feet of metal surface and a "slickensided" effect has been produced which makes the chance of its healing perfectly even more remote. In the case of augers with two or three threads, we simply have two or three ribbons of clay superimposed but producing the same defect. The advantage of more threads is to give a steadier flow. With the single thread, if the nozzle and die of the machine are both short, the single discharge of the auger, moving in a circle, will be followed at 180° by a point of no pressure which will cause the column

to oscillate from side to side and produce ribs on the surface of the ware. With a longer nozzle and die this defect can be partially and sometimes wholly eliminated. The imperfect healing of the spiral ribbon of clay itself must be effected through pressure, and the pressure must be considerable to bring about any healing whatever.

Since the stiff mud clay column is fluid enough to tend to obey the law of fluids, we have another and more serious defect produced in the nozzle and die after the clay has left the auger. It is the defect known as die lamination. This defect is caused by the more rapid movement of the center than the outside of the column, and manifests itself in cleavage planes more or less parallel to the length of the column. This differential movement is caused by the friction of the clay bar upon the die; and the remedy, which means uniform movement over the whole area of the cross-section of the bar, can be effected partially by reducing the die friction to a minimum by means of lubricators and also by a smaller taper in the die and nozzle. Since this friction cannot be wholly eliminated, this differential movement in the bar cannot be wholly overcome, though it can be reduced to such small proportions that the defect is not physically noticeable in the product. The corners, of course, are held back most, but they can be relieved by so distributing the lubricant that the corners receive the most, or, in the case of dry dies, by cutting out the corners so that more pressure will be effective at these points. This defect of die lamination is particularly pronounced if the auger is too small in diameter.

It has been intimated in the foregoing that considerable pressure is required to heal the clay column of its auger and die laminations; but it must be borne in mind that while a certain pressure will give the best results, any more would be simply a waste of power, for water is incompressible and clay is likewise practically incompressible. When sufficient pressure has been applied to force the clay particles into close contact by the removal of the air, any further application is just a waste of power. It is practically impossible to squeeze water out of clay if the water has been properly tempered into the mass.

The amount of pressure applied by any particular auger is governed by the resistance offered to the flowage of the clay by the nozzle and die. The clay, being an imperfect fluid, transmits part of the pressure from the auger in every direction; and as the auger pressure is increased, the pressure against the walls of the nozzle and die increases, causing greater frictional resistance to the clay bar. These lamination defects are produced after the granular plastic clay has been compacted into the ribbon delivered by the auger. The preparation of the clay with-

in the limits of the ordinary preparation given to clay affects the degree of lamination to only a very limited extent.

The primary causes of lamination as we have pointed out are three; the stiffness of the clay bar, which prevents perfect healing between two surfaces in contact; the differential flow in the bar itself due to frictional resistance along the periphery; and the rotative tendency imparted to the clay by the auger, not one of which it is possible to wholly remove. Owing to the different physical characteristics of different clays, it is possible with some to reduce the lamination to almost a negligible quantity. Strength and plasticity seem to be the two physical properties which most affect these defects. The stronger a clay, the less likelihood is there that the differential flow will break the clay bond and manifest itself in cleavage lines or laminations, and on the other hand the more plastic the clay, which is usually accompanied by greater strength, the more like a fluid it acts, causing greater differential flow not alone because of its greater fluidity but also by causing greater peripheral friction. Clays of very low plasticity are least subject to lamination. Such clays are usually low in strength and the forces producing lamination manifest themselves in ragging the corners or breaking the bar transversely.

From these considerations, it is evident that one of the simplest methods of reducing lamination in a clay of average plasticity is to temper the clay to a wetter consistency, in which condition it would require less pressure for the formation of the bar, and the ribbon delivered by the auger would heal more perfectly. The temper to which the clay may be pugged is governed almost wholly by the softness at which the product can be handled from the machine to the car and retain a perfect shape. The supposed disadvantage of having that extra amount of water to evaporate in the drier will be spoken of later. A reduction in the tendency to laminate is also accomplished by cutting down the taper to the nozzle and the die, thereby reducing the lateral pressure and the incident friction.

Our considerations thus far have pointed to the fact that any pressure above that which is actually necessary to remove the air from the granular clay and cause a solid ribbon to be delivered by the auger is superfluous. This is not exactly in accord with the average brickmaker's conception. It is commonly supposed and has frequently been written that the greater the pressure used in forming a plastic clay the greater the density of the product. However, a statement was made by Dr. Seger some forty years ago, to the effect that from theoretical considerations it was evident that no increased density is obtained by repressing. This was on the assumption that the repressing

was done under great pressure. Recent work done to test the accuracy of these theoretical considerations have proven beyond a doubt that repressing, even under pressure as high as 1500 pounds per square inch, serves no other purpose than to give a true square shape to the brick, which can be accomplished just as well at very low pressures. Even at the highest pressures used no change in porosity, which is a measure of density, could be noticed from that of a brick molded by hand, under no pressure, from the same clay. (Parmlee Vol. XVI. Trans. ACS.) If pressure has no more effect than this in the case of repressing, it reasonably follows that in the auger machine pressure can accomplish little more useful work than to remove the air and give a true shape. While some pressure is necessary to properly heal the ribbon delivered by the auger, increasing pressure increases the peripheral friction.

This discussion has not pointed out any definite pressures as sufficient or excessive for each clay. Its own properties will determine what pressure produces the best results.

DIES.

The principal difference in the several types of dies is in the method of lubrication. We have the dry die, the water lubricated, the steam lubricated, the oil lubricated, and, to complete the list, we should add the electric method, though it is of but little importance as yet.

The characteristic difficulties with clay flowing through a die have been described. As the flow of the bar is most rapid in the center, anything which reduces the surface friction will tend to equalize the flow. On the same principle, the flow of the clay along the side is more rapid than at the corners, and withholding the sides tends to produce equality of surface flow. There are two methods of attaining this end; (1) by cutting away resisting surfaces at one point and adding them at another. (2) by lubricating. These two methods are directly opposite. Lubrication reduces the friction at the slow point of flow; resistance holds back the flow at the most rapid.

In proportioning a die by the resistance plan, all possible metal is cut away at the point of the slow flow, such as at the corners of a brick die. While increasing the actual amount of friction, this process reduces it in proportion to the increased area.

In connection with the dies for fireproofing, conduits and similar hollow wares, as well as for sewer pipe, the study of surface flow becomes more complicated than in the production of a solid bar. In general the method resolves itself into the idea of cutting away and inducing easier flow in the different parts rather than actually adding resistance at those parts that

flow most easily. Either method would accomplish the same results.

The flow of a bar of clay through a die is greatly facilitated by the presence of some liquid between the clay and the metal. Any liquid is an assistance though some are better than others. While many have been tried, still the most satisfactory seem to be water and oil. The oil is essentially either crude oil or kerosene, or kerosene containing various proportions of the heavier or fatter oils such as castor or machine oil. The most preferable of all is lard oil, but its price renders it out of the question. In certain cases it is possible to use a solution of soft soap, and the use of crude ammonia liquor has been tried.

These lubricants may be applied in different ways; (1) over the entire surface of the bar, in which case it simply facilitates the flow of the bar as a whole, leaving the same relative disturbances of surface flow as if no lubricant has been applied, though it does reduce the differential flow between the center and the surface of the bar; (2) it may be applied locally to facilitate the flow of portions which tend to hang back, leaving other portions unlubricated. This is the preferable method.

The lubricant may be applied as either a liquid or vapor, or the moisture supplied by the clay itself may be made to appear on the surface of the clay by the use of steam heated dies. In the last mentioned case, the cold clay coming into contact with the hot die causes some of its water to be converted into steam or hot vapor at the point of contact, and this seems to answer the same purpose as if additional water had been added.

The use of lubricants sometimes causes defects in the clay bar. Many clays not suited to the auger machine still crack after passing the die whether it is lubricated or not. Lubrication will not correct a severe defect in the workings of a clay. If oil is used, it is very likely to enter these cracks and prevent the possible healing in the subsequent handling or repressing. Occasionally repressed brick on being broken open show dead spots covered with a glistening film of carbon, which is due to the oil from the die entering the crack and being coked there. For this reason, oil, though more efficient, is more objectionable than water. When water is used it may enter the cracks in the same way, but the pressure of water facilitates rather than prevents healing. For clays that are well suited to auger machine work, no lubrication whatever, except that induced by the hot die, is necessary. Unfortunately the number of clays possessing the right balance between cohesive strength and plasticity is not large, so that many clays used in auger machines require careful lubrication to get successful working. In general this

is caused by too much fine non-plastic matter and too little clay substance.

DRYING.

Clay wares in the plastic condition have yet to be subjected to a hardening process to render them serviceable. This hardening consists in, first, the removal of volatile ingredients, and, second, the combination of the remaining into a more or less homogeneous, complex silicate mass. A part of the removal of the volatile ingredients is accomplished in drying by purely physical means, and the rest in burning, through both physical and chemical processes.

Drying may be viewed from two standpoints, that of the physicist and that of the clay worker. In the former we deal with the actual quantities of heat and air necessary to accomplish a given amount of evaporation. In the latter we determine in what manner this evaporation must proceed in order to produce sound, strong ware. It is impossible to order a drying operation strictly along the lines of physical economy. Nevertheless, without some conception of the economy, the methods actually used are liable to become needlessly wasteful.

EVAPORATION AND VAPORIZATION.

The removal of water by means of heat from the plastic clay, from any moist substance, or even from a container, may be accomplished in two ways, by evaporation or by vaporization. There are distinctions between the two which it is well to have in mind. Evaporation may take place at any temperature below boiling. This phenomenon is confined to the exposed surface of the liquid, i. e., the conversion of water to vapor takes place only at and from the surface that is exposed to a gaseous medium. It can continue only until the surrounding medium has become saturated. Vaporization, on the other hand, takes place only at or above boiling, which is at sea level 212° F. This phenomenon is not confined to the exposed surface. The conversion of water to vapor takes place throughout the whole body of the liquid. The vapor forming within the liquid rises to the surface as a bubble and then passes off into the air. Vaporization requires that the temperature of the liquid and the pressure to which it is subjected be brought into such relation to one another that the vapor tension of the liquid exceeds the pressure. This means a temperature of 212°F. under atmospheric pressure at sea level, a lower temperature in higher altitudes or in partial vacuum, and a higher temperature where the liquid is confined under pressure greater than atmospheric. Evaporation is the process with which we have to deal in studying the drying of clays. It takes place at all temperatures below boiling and re-

quires a continual change of surrounding atmosphere. The reason for the necessity of changing the atmosphere to effect continuous evaporation is found in aqueous tensions. Water vapors at all temperatures exert certain pressures or tensions which limit the amount of evaporation that can take place. This pressure, known as aqueous tension, varies with the temperature, being very small at 32° F., thus allowing very limited evaporation to take place, and 170 times as high at 212° F., thus allowing very rapid evaporation. Obviously, as the atmospheric pressure changes, the aqueous tension at boiling changes, for boiling takes place when the aqueous tension is sufficient to overcome the atmospheric pressure or whatever may be the pressure of the medium surrounding the vaporizing liquid.

The prime object to be obtained in the drying of clay wares is to produce a sound, strong, product, and, since the rate of evaporation of the contained water affects the soundness and strength, the temperature and degree of saturation of the surrounding atmosphere is of importance. The conversion of water into vapor requires a certain amount of heat which disappears from our senses without effecting any measurable change in temperature. This is called latent heat of vaporization. In addition to this a certain amount of heat is used in raising the water to the temperature at which vaporization takes place. The total amount of heat consumed increases slightly with the temperature at which the conversion is made, being greatest when made at the boiling point.

HUMIDITY AND DEW POINT

When a fixed, unchanging volume of air surrounding a wet clay lump becomes saturated, a state of equilibrium obtains which is affected only by changing temperature. If the temperature is raised, further evaporation takes place until equilibrium is again reached. This point of complete saturation, at which any lowering of temperature would cause deposition of dew, is known as the dew point. Humidity is that quantity of water vapor contained by any given atmosphere at a given temperature, expressed as a percentage of the amount that could be held at the same temperature at the dew point. The amount of water vapor that can be held by the air without deposition of dew increases with increasing temperature. The humidity of a given volume of air may therefore be lowered by raising the temperature. The average humidity throughout the year for this section of the country is about 75°, making the atmospheric air only one-fourth as effective as dry air at the same temperature. Dry air, however, cannot be obtained by heating, for while heating makes the air more effective as a drying agent, it is accomplished by making the air capable of carrying more

water vapor without diminishing the amount it already contains.

Thus it is seen that it is possible from a physical standpoint to determine absolutely what heat must be used to "evaporate" a given quantity of water and what degree of economy is being obtained in any given drying plant. When the facts are known as to temperature and humidity and volume of the incoming and outgoing air, if the highest possible fuel economy in the clay dryer is attempted, it is not only possible but probable that the clay wares would be utterly ruined by cracking, discoloration and other defects.

In drying clothes in a laundry, or paper in a paper mill, or slurry in a cement works, where the problem is one of evaporation only, a dryer could be proportioned on strictly physical considerations; but in drying clay wares the first and principal consideration is always the ware itself and how best to remove the water while still preserving the strength, color and shape. In short, economy of fuel is always a secondary and often a very unimportant consideration in drying clay wares; but it must be had in mind that it is often possible to greatly improve the heat consumption and the physical side of the process without injury to the quality of the ware.

The differences in treatment required in drying operations are not arbitrary or irrational peculiarities; they proceed from differences in the physical structure and characteristics of the clays themselves. The fatter a clay is, i. e., the more plastic clay substance it contains, the more water it will take up that will have to be removed in the drying operation. Any addition of non-plastic matter reduces the amount of water necessary for maximum plasticity, reducing in turn the amount of shrinkage. At a moderate fineness its reduction of shrinkage and water content is greatest.

Here it is well to point out another respect in which the drying of clay wares becomes a more difficult problem than simply that of the evaporation of a given quantity of water. The physical laws employed to determine the quantities of heat and air necessary to perform a given amount of drying are the same as those used to determine the quantities of heat and air necessary to evaporate a given amount of water from a container, disregarding a certain affinity which clay has for water and the tenacity with which the clay tries to retain it. It is practically impossible to squeeze water out of clay. It can be accomplished only under enormous pressure when the clay is very wet. A centrifugal force of about 3,000 times that of gravity has been found insufficient to remove all the water from the soil. This force with which the clay tends to hold the water

becomes effective when a certain optimum of water content is reached. Up to that point the quantities of heat, time and air necessary to remove the water are calculable, for the water removed is that filling the coarser pore system and is removed through practically unhindered evaporation. When the water from the coarser pore system has been removed however, the process is no longer that of simple evaporation such as the evaporation of the last drop of water from a pan. Below a certain moisture content the rate of evaporation decreases because the water vapor diffuses more slowly from the finer capillary spaces and because the increase film tension due to the thinner films causes a decrease in the vapor pressure of the film water.

Thus it reasonably follows that under ordinary drying conditions such as obtain in the average commercial dryer, the time required to dry a certain ware, is not greatly affected by the total amount of water in the clay, within the limits for stiff mud manufacture, for the heat and time required to remove the water which is tenaciously held by the clay (which in a stiff mud product is nearly 100° of the tempering water) is much greater than our calculations on the basis of the laws governing evaporation would indicate, and any additional water is removed with a smaller expenditure of time and energy. This fact is clearly indicated in the drying and experiments recently made by Professor Staley, in which a series of briquettes were made up from the same clay using different amounts of tempering water. They were all dried at the same time under the same conditions, and the drying of all was complete in the same length of time. The briquettes having the least water seemed to have no advantage in respect of time of drying. And again, the drying curves plotted from the time and water loss record, obtained from weighing at frequent intervals, showed that when a certain water content was reached, the drying of all the briquettes proceeded along the same curve.

That every clay presents its own drying characteristics is evident from some of the markedly peculiar properties exhibited by some clays, among which could be mentioned the very fat, sticky, glacial clays found in some parts of southern Minnesota and northern Iowa, and some of our common, short, fine-grained loess clays. Both present very poor drying properties requiring exceedingly slow drying to insure sound ware; in fact with some of the sticky, glacial, joint clays it is almost impossible to dry them slowly enough to prevent cracking. The reason seems to be found in the excessive stickiness and fineness of grain and the joint structure which it is found quite impossible to obliterate by any amount of working. The remedy for these drying difficulties, which will make most of these clays usable, is ob-

tained in preheating. The clay before tempering is preheated 400° to 500° F., the exact temperature depending upon what is found best for the particular clay. This reduces the plasticity and stickiness and destroys the joint structure to some extent, making the clay safe drying. However, all clays of this class are not rendered usable by this treatment. Some require such a high temperature of preheating to bring about safe drying that the plasticity is reduced to practically nothing.

The short, fine-grained loess clays present peculiar drying difficulties. The surface dries out very readily causing pronounced cracks to open up while the interior is still wet and plastic. This seems to be due to a peculiar pore structure which allows a very rapid evaporation of the water. It may also be due in part to the character of the clay or sand particles in that they do not hold the water very tenaciously. It also seems probable that this surface drying so alters the character of the surface shell that the evaporation of the water from the interior is retarded, either by a closing-up or filling-up of the pore system. A remedy for this defect may be accomplished by the addition of common salt during the tempering process in the proportion of from 5 to 10 pounds to the ton of clay.

Of the three most common methods of supplying heat to the drying operation in Iowa, each has its particular advantages, but each also has its disadvantages. By the burning of fuel directly for the purpose we probably arrive at the most thorough control with the least waste of heat. In the case of steam drying, good control is obtained, but there is an opportunity for greater waste of heat by condensation. Both of these methods require an expenditure of fuel. With the use of waste heat from the kilns less definite control of the drying conditions is obtained, although there is the advantage of using heat that would otherwise be wasted. It does, however, necessitate the expense of operating the fans, which is no small item as compared with the small amount of fuel used where it is burned directly for the purpose.

III. THE PHYSICAL AND CHEMICAL CHANGES IN CLAY DURING BURNING.

Homer F. Staley.

INTRODUCTION.

The burning of clay wares by no means consists simply of the application of heat to an inert mass. From the chemical standpoint a piece of raw clay ware is made up of a large variety of elements in various states of combination. During the burning some of these will be expelled, others will be taken up from the combustion gases, and there will be a general rearrangement in state of combination of the elements.

From the physical standpoint, a soft friable mass, held together by a plastic band, must be converted into a hard resistant body held together by a vitreous bond, and this without loss of shape. While this transformation is taking place, large volumes of gases must be expelled through the pores of the clay, others must find their way into the very center of the mass and the piece of ware will decrease in size from 15% to 30%.

In fact, the burning of clay wares is a very complex entanglement of chemical and physical processes. The processes themselves can never be made simple; but with a proper appreciation of the nature of these, it is possible for us so to control the burning as to attain the results desired in the most expeditious and economical manner.

The burning of clay wares may, as a matter of convenience, be divided into three periods:

Dehydration, Oxidation, Vitrification.

THE DEHYDRATION PERIOD.

This period extends from the start of the burn to the point at which the last of the combined water in the clay is expelled, that is to dull redness, about 1400° F. or 750° C. This period may be subdivided as follows:

Mechanical dehydration or watersmoking—300° F., 150° C.
Chemical dehydration 300° F.—1400° F, 150° C.—750° C.

Watersmoking. As the term is used here, watersmoking is the completion of the drying process, being that portion of the drying that must be done in the kiln. The amounts of water in the ware as it goes to the kiln will be somewhat as follows:—

	Maximum	Minimum	Average
Dry press	14%	7%	9%
Stiff mud from hot dryers	8	2½	3
Stiff mud from cool and natural dryers	9	5	6

In addition to the above, a large amount of water enters the kiln in the air used for burning, and a certain amount is produced by the combustion of hydrocarbons in the fuel.

While the amount of drying to be done in the kiln is always considerable, the ordinary kiln makes a very poor dryer for the following reasons:

1. The ware is closely packed in one large mass.
2. It is impossible to apply the heat uniformly to all parts of the ware at once.
3. It is difficult to draw the heat in mild and uniform progression to the various parts of the ware.

As a result of the above conditions, popping is liable to occur in the ware closest to the source of heat; and condensation of water and acid dew is liable to take place in the colder parts of the kiln. These conditions are especially liable to prevail if the products of combustion are quite hot and small in volume.

The condensation of water tends to cause the ware to warp out of shape, especially if it is carrying a heavy load of superimposed ware. The condensation of acid dew is sure to cause scumming. The acid dew consists of water and sulphurous acid, formed from the sulphur compounds in the coal. When either of these acids comes in contact with a clay containing calcium

Fig. 1. Curve showing the oxidation of carbon in the burning of a clay.

or magnesium, a white scum is formed. Since all clays burned in open kilns contain enough magnesium and calcium to form a scum, we may say definitely that whenever acid dew condenses on raw wares scumming takes place.

The following conditions tend to minimize the difficulties of watersmoking:

1. Ware as dry as possible.
2. A large amount of air mixed with the products of combustion.
3. Rapid travel of gases through the kiln.
4. Upward travel of gases.
5. Fuel low in sulphur and hydrocarbons.

The means of producing these conditions will be discussed briefly.

1. It is not possible to set perfectly dry ware in a kiln. No difference how thoroughly the ware may be dried in the dryer, as soon as it is exposed to the atmosphere, it will re-absorb water to the extent of 2% or 3% of its own weight without being sensibly damp. This is due to the tendency of any fine grained material to become covered with a film of water when in an atmosphere containing moisture. This water is called hygroscopic, and its presence is unavoidable.

However, ware is often set in the kiln while containing five or six per cent of water in addition to the hygroscopic water. In this case either the kiln must be converted into a dryer, for which purpose it is poorly adapted as shown above, or some ware must run a big chance of being ruined. The worst condition is when part of the ware in a kiln is dry and part is damp. This usually happens when there is a "hurry" to get the ware burned. It is really a good method to "make haste slowly". It will take much longer to dry the ware poorly in the kiln than to dry it properly in the dryer. However, in such cases usually only a nominal attempt is made to really dry the damp ware, and the burner proceeds to watersmoking. The result is that the damp ware hangs behind the rest of the kiln during the whole process of burning and is very liable to prove defective in each of the stages. In the watersmoking stage the damp ware, being cooler than that surrounding it, is especially liable to serve as a point of condensation for acid dew. This is the basis of the notorious tendency to scum in ware set while damp.

2. A large amount of air mixed with products of combustion is easily obtained by allowing air to pass in over the fire.

3. A rapid travel of gases through the kiln necessitates a strong draft. A chimney gives a strong draft only when it is filled with hot gases. Since the gases coming from the kiln at this period are not hot, a stack or stacks connected only to the
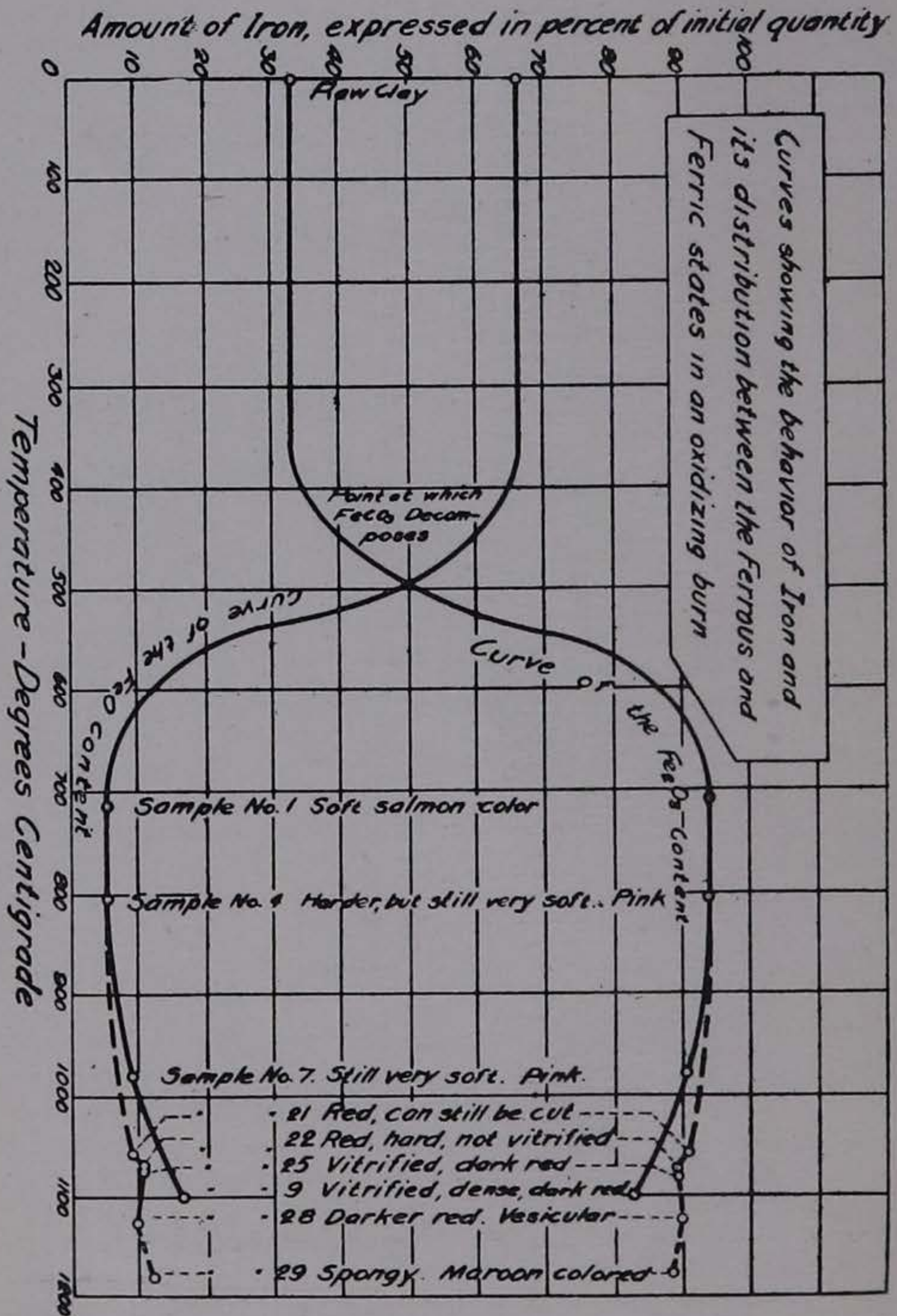
Fig. 2. Curves showing the behavior of iron in the burning of a clay under oxidizing conditions.

watersmoking kiln will not give the desired amount of draft.

Remedies are:

(a) Compound stack. Here are more than one kiln being

taken care of by the same stack. If one of the group of kilns is on high fire while another is watersmoking, there will be an equalization of draft which will be beneficial to both. The difficulty with this arrangement is that it makes it difficult for the burner to get accustomed to the variations caused by different combinations.

(b) Use of a fan for draft during watersmoking. This is a satisfactory method.

(c) Building a fire in the base of the chimney to heat up the products of combustion and cause a draft. Simple and fairly effective if fire is large and hot. This is main point of advantage in a couple of patented kilns widely exploited at the present time. The idea itself, however, is old and hardly patentable. Multiple stacks are not desirable at this stage of the burn as there is a tendency for reverse draft to form in some of these.

4. Upward travel of gases through the ware may be obtained either by the use of updraft kilns or the so-called up and down draft kilns. In either case the length of the watersmoking period is shortened and the tendency to scumming is much re-
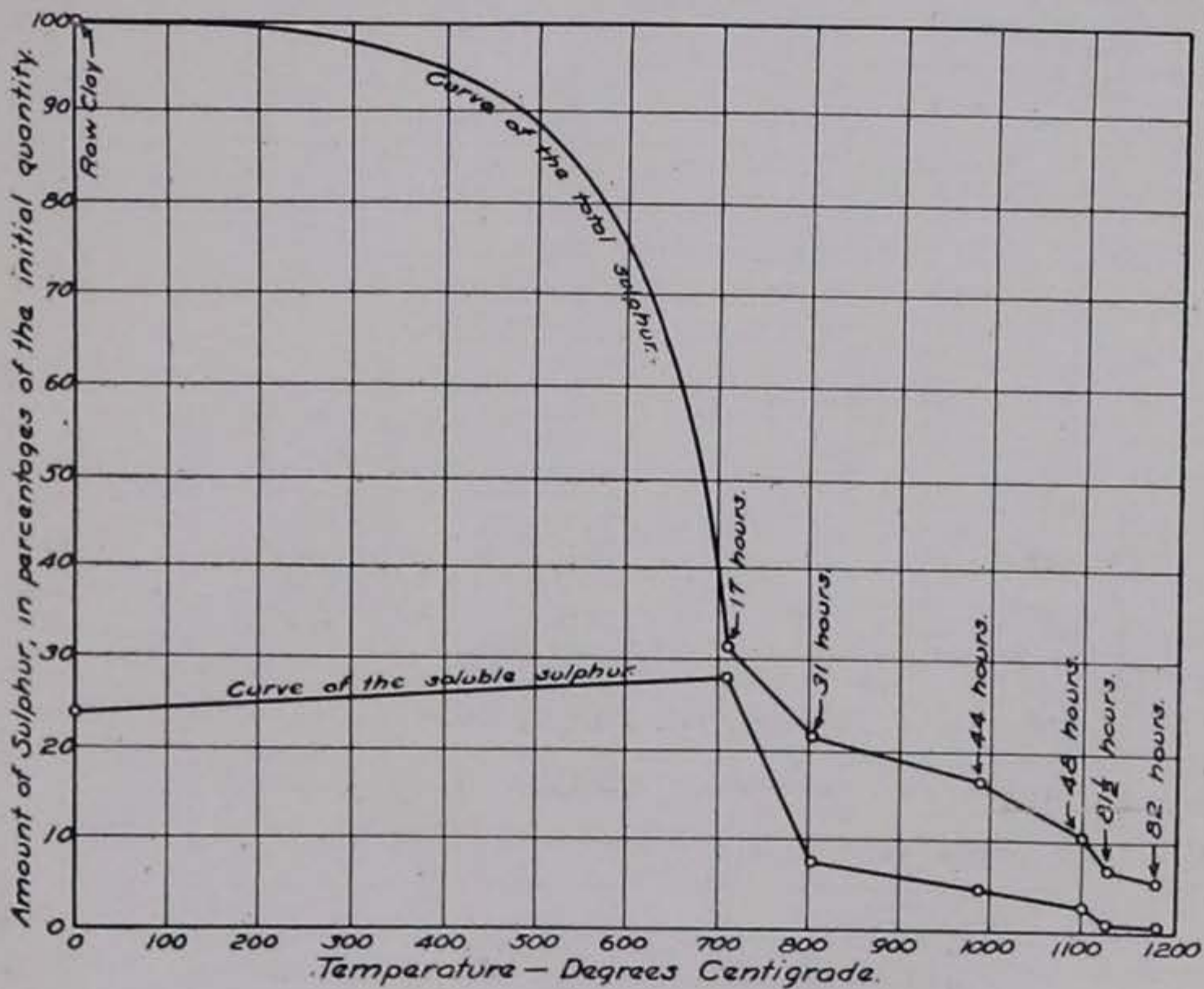
Fig. 3. Curves showing the behavior of sulphur in the burning of clay under oxidizing conditions.
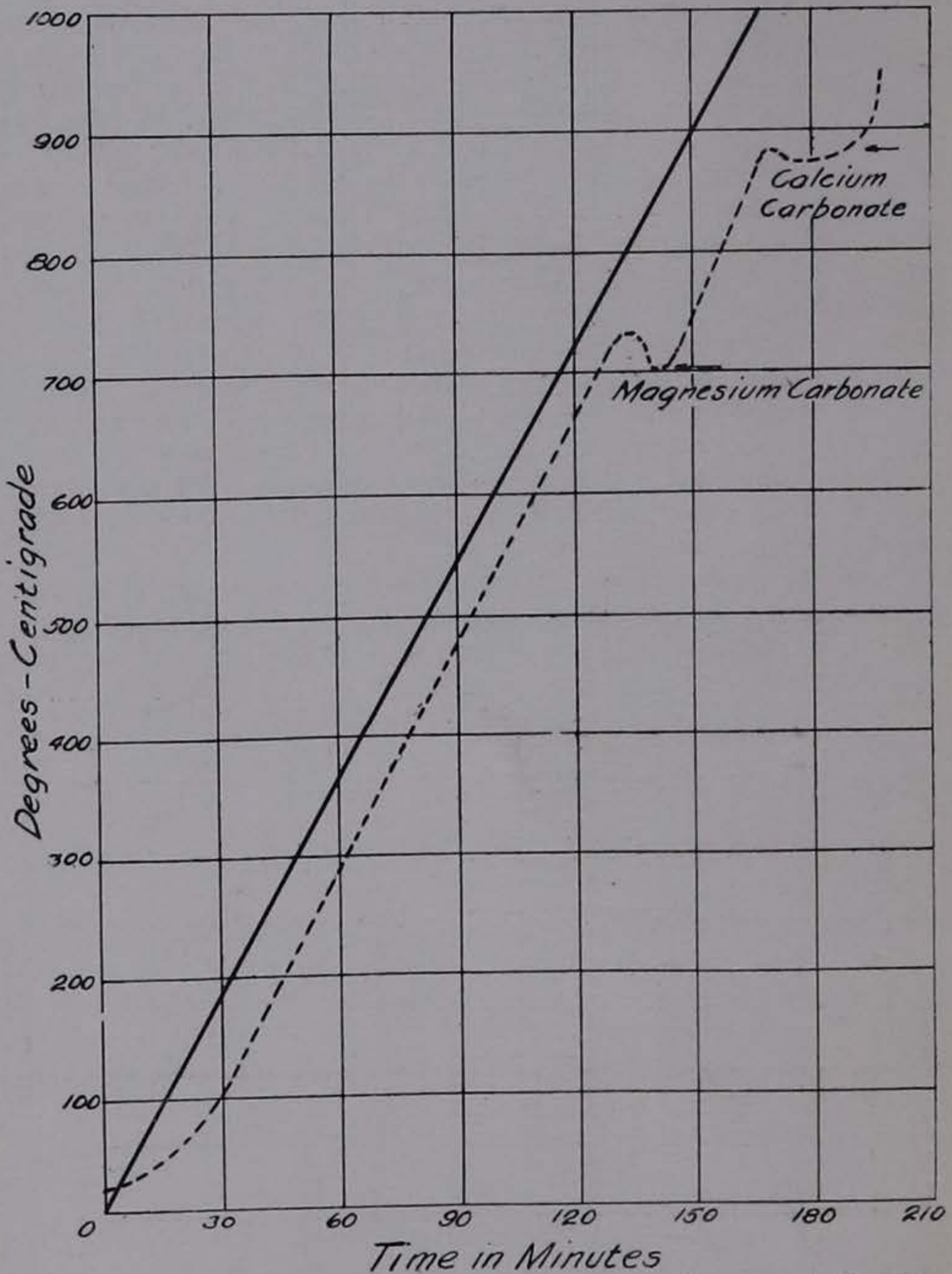
Fig. 4. Heating curves of calcium and magnesium carbonates which indicate by the breaks in the curve the dissociation temperatures of CO_2.

duced. Draft is started quickly and condensation is a rare occurrence.

5. A fuel low in sulphur is desirable because the sulphur causes scumming. A fuel low in volatile matter is desirable because volatile hydrocarbons form water when they burn, according to the reaction:

$$CH_4 + 2O = CO_2 + 2H_2O$$
$$16 \quad 64 \qquad 44 \quad 36$$
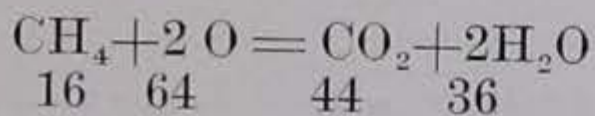
On burning a ton of coal containing 30% volatile matter, there is manufactured 1350 pounds of water. It will take 135 pounds of coal to evaporate this and expel it from the kiln. Coke is the best fuel for watersmoking, because it is low in sulphur and forms little water. Wood is free from sulphur but contains and generates an enormous amount of water. In this region a good short flame coal is probably the best fuel available. It should be realized that the watersmoking period requires really better fuel than any other period of the burn.

The watersmoking period ends at about 300° F. Water in an open vessel will boil at 212°F., but the small amount of water in the fine pores of a piece of clay ware, or present as fine films of hygroscopic water on the surface of the grains, is held tenaciously by the clay and is not all driven off until temperatures of 300° F., or higher, are reached.

At the end of the watersmoking period, the ware, except
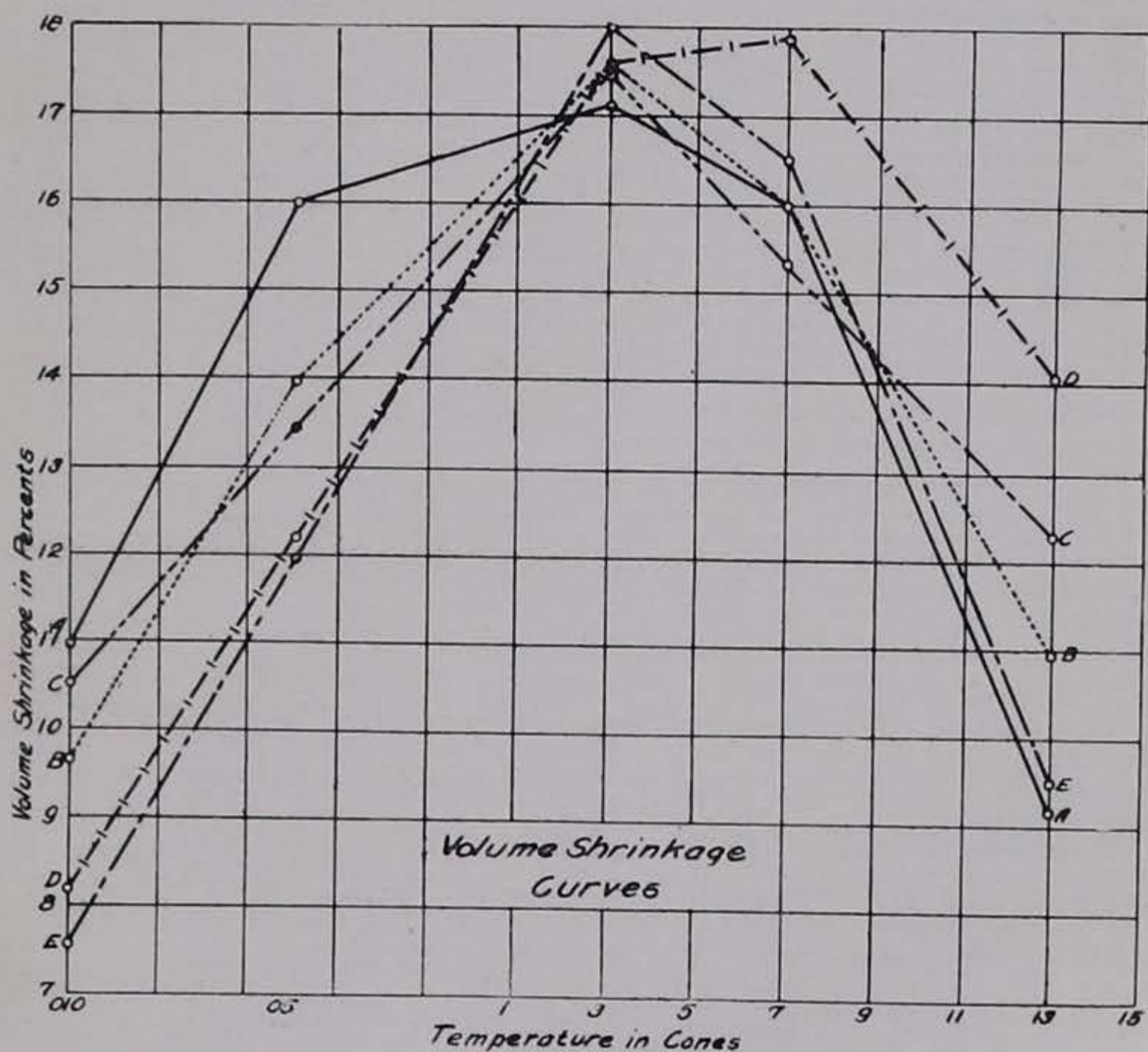
Fig. 5. Curves showing the volume changes of two fire clays and three fire clay mixtures during the progress of the burn.
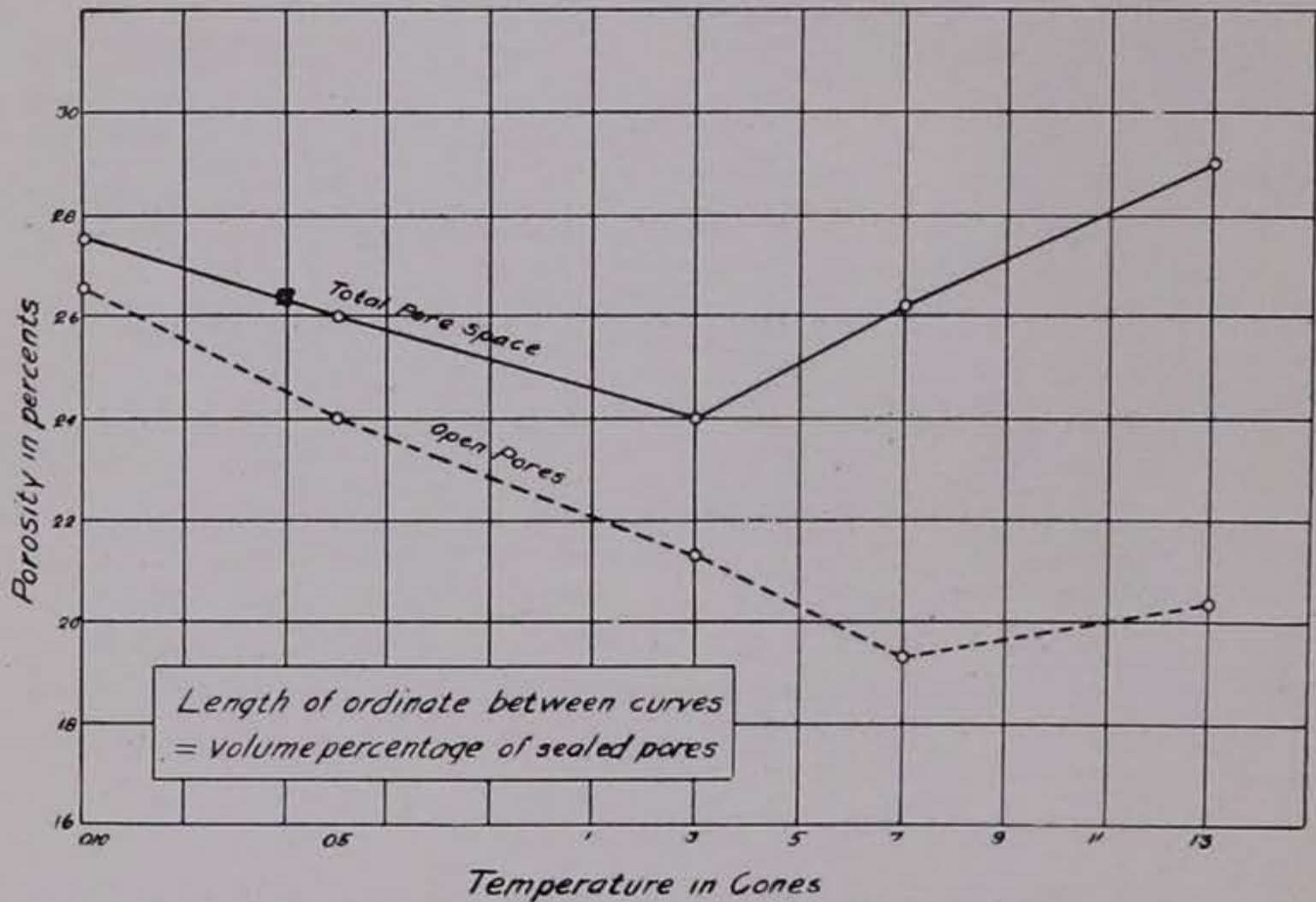
Fig. 6. Curves showing the distribution of pores between "open" and "sealed" during the burning of a fire clay mixture.

for the loss of mechanically held water, should be physically and chemically the same as when it went to the kiln. The only noticeable volume changes would be those due to bloating and popping, and the only chemical reaction would be that involved in the formation of scum due to the condensation of acid dew.

Chemical Dehydration. While we speak of this period as chemical dehydration, there are really several reactions that may take place depending on the composition of the clay.

These are:

1. Combustion of carbonaceous matter.
2. Distillation of half the sulphur from pyrites.
3. Dehydration of kaolinite and other hydrous minerals.
4. Breaking down of iron carbonate.
5. Reduction of iron compounds.

1. *Combustion of Carbonaceous Matter.* The carbonaceous matter in clays may consist of any or all of the three following classes:

(a) Fresh vegetable tissue, roots, leaves, etc.
(b) Bituminous and asphaltic matter.
(c) Graphitic matter.

The small amounts of roots, leaves, etc., found in clays burn out at low temperatures without doing harm.

Under the action of heat, bituminous and asphaltic matters break down into highly combustible volatile hydrocarbons and a residue of graphitic or coke-like carbon. The burning of these

hydrocarbon gases in and around the ware produces an intense heat. If they are present in any appreciable amount—2-6%—and their volitalization is not controlled, the result will be a kiln of bloated and warped ware. The proper procedure is to cut down the air supply to the point at which the evolution and combustion of the gases take place at a safe rate. It may take five or six days to do this. In England, wares made from bituminous shales are burned in this way with the use of practically no fuel. However, with fuel as cheap as it is in most parts of this country such a procedure would be poor gambling.

Graphitic carbon burns out slowly without flame, but with a simple glowing. The only necessity is that sufficient time be given for its complete expulsion at a good red heat. In fact, most of this kind of carbon is not expelled until the oxidation period.

2. *Distillation of Sulphur from Pyrites.* Pyrites, Fe S_2 consists of one molecule of iron and two of sulphur. By simply heating it at temperatures around 850°F., one molecule of sulphur is driven off, leaving the other molecule combined with the iron as FeS. In a kiln the sulphur driven off unites with oxygen forming SO_2 or SO_3 which passes out the stack. The FeS remains in the clay until the oxidation period is reached.

3. *Dehydration of Hydrous Minerals.* These minerals are kaolinite, (by far the most abundant) other hydrous silicates, limonite, talc, mica, etc. The chemically combined water in all these passes off quietly at temperatures between 300° and 1400° F., without doing any damage. The theory that the expulsion of water of combination from clay causes swelling is no longer tenable.

4. *Breaking Down of Iron Carbonate.* The carbonates commonly found in clays are those of iron, calcium and the double carbonate of calcium and megnesium, called dolomite.
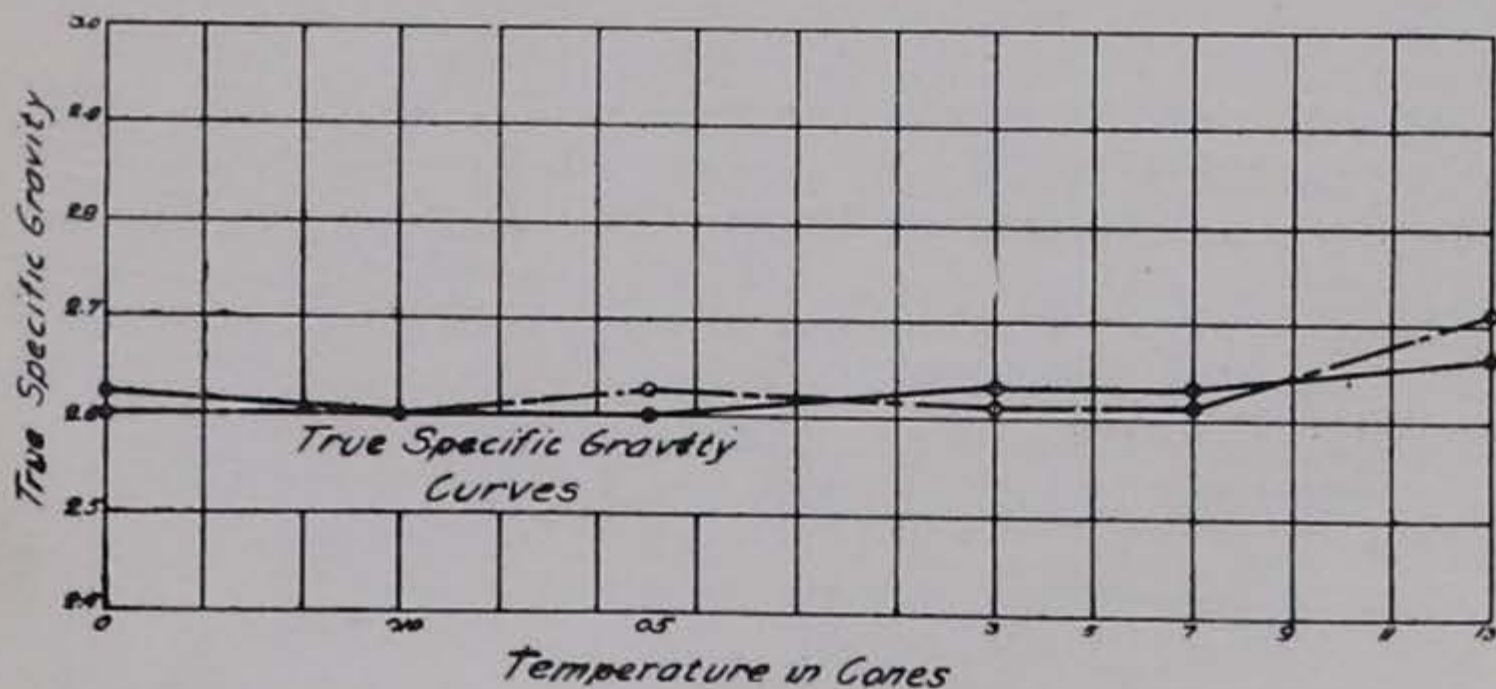
Fig. 7. Curves showing the true specific gravity changes of two fire clays up to cone 13.

The decomposition of iron carbonate takes place quietly around 700°F., with the formation of CO_2 gas and ferrous oxide. The other carbonates do not decompose until the oxidation period.

Heat Treatment During Chemical Dehydration. The process of watersmoking is necessarily slow, but as soon as no more water can be detected in the flues by inserting a cold iron, we can cut down excess air and begin to raise the heat quite rapidly. In fact it is almost impossible with many clays to raise the temperature too fast during this period, although of course it might be done. With large pipes made of dense clay "slabbing" may occur, and, of course, if the clay contains volatile combustible matter, the temperature must be raised slowly. The chemical water is being given off at this time, but the clay is quite porous and the water is generated slowly so that there is little danger of popping due to steam. Horizontal gates are superior to inclined grates at this period, since it is easier to raise the temperature readily with them than it is with inclined grates. The disadvantage of the ordinary grate furnace at this period is that it takes a long time to build up the fires to a point at which the excess air can be cut down to a minimum. In fact, in most cases the excess air is not cut down until the end of this period. Excessive air at this stage is unnecessary and is wasteful of fuel and time. A simple door or plate to place over the mouth of the fire box will help to save time and fuel.

End of Period. During the dehydration period, the clay has lost all of its water, half the sulphur from the pyrites, all of its organic and volatile carbon, and part of its CO_2. It still contains, as impurities to be removed, graphitic carbon, sulphur in the form of FeS, and part of its CO_2. From the physical standpoint, the ware is at its most porous state. To the pores it contained when the last of the hygroscopic water was driven off, have been added those produced by the expulsion of the various ingredients we have been discussing. Shrinkage has not begun. In fact, in most clays a slight swelling is noticeable.

OXIDATION PERIOD.

The objects aimed at in this period of the burning is to get rid of CO_2, carbon and sulphur, while the clay is still porous, so that they will not produce swelling by forming gases after the pores of the clay begin to close up in the vitrification period; and to convert all the iron from the ferrous to the ferric state so that the ware will not have a black interior when vitrified.

The lower limit of the oxidation period is fixed at about 1400° F., by the fact that up to that time such a copious flow of various gases, chiefly steam and CO_2, is coming from the clay that only a small amount of oxidizing gases can work in. The upper limit is fixed around 1650° F., first, by the fact that many

clays begin to vitrify and have their pores closed at that temperature, and, second, by the difficulty of maintaining thoroughly oxidizing conditions at temperatures much above 1650° F.

The following chemical changes take place during the oxidation period.

Expulsion of CO_2. Formerly calcium carbonate and dolomite were supposed to lose their CO_2 during the dehydration period. Later work has shown that dolomite does not lose its CO_2 below 1400° F., and calcium carbonate below 1600° F. The CO_2 goes off quietly without doing any harm. Clays high in lime must be held at 1600° F. or a little above until all CO_2 is out.

Oxidation of Carbon. The carbon present in the clay at this period is in the form of graphitic carbon. At bright red heat and in oxidizing atmosphere, it slowly burns to CO_2 gas which passes off. This reaction is delayed by the presence of carbonates in the clay.

Oxidation of Sulphur. The sulphur is present as FeS. Since carbon has a greater affinity for oxygen than sulphur has, little sulphur will be oxidized until practically all the carbon is burned out of the clay. It will then be slowly oxidized, but the last traces are very difficult to expel, and a clay high in sulphur is liable to bloat unless excessive time is given for oxidation.

Oxidation of FeO to Fe_2O_3. Some white-burning, most buff-burning, and practically all red-burning clays contain enough carbon and sulphur to reduce all iron present in them to the ferrous form. Since carbon and sulphur both have stronger affinities for oxygen than ferrous oxide has, the oxidation of the ferrous oxide does not take place until all the carbon is expelled and most of the sulphur. It is then gradually changed in an oxidizing atmosphere to ferric oxide.

It is apparent that the function of the oxidation period is, as its name implies, to furnish oxygen to every part of the clay wares. The rate at which oxidation takes place will depend on:

1. The presence of other gas forming materials in the clay ware. This has been discussed.
2. The structure of the clay ware. The denser the structure the slower the oxidation.
3. The temperature. The higher the temperature the more rapid the oxidation.
4. The amount of oxygen in the kiln gases.

Heat Treatment During Oxidation Period. The limits of 1400°—1650° F., have been given for the oxidation period, but in reality the bulk of the oxidation should take place at a point in temperature rather than over a range of temperatures. This

oxidation point must be slightly below that at which vitrification begins, but as close to it as is consistant with the use of considerable air excess.

The one important consideration at this stage is to have a liberal supply of hot gases carrying considerable oxygen. This means that there must be good clear free-burning fires. The draft should be strong, the grate bars clean, and the fires should be baited lightly but at frequent intervals. As far as is possible smoke should be avoided. When bituminous coal is used, a coking plate is to be recommended.

A coking plate is, of course, a solid platform inside the fire box on which the fresh fuel can be laid and allowed to generate its volatile combustible matter slowly. This volatile matter passes directly over the bed of hot fuel and burns without producing the smoke it would if the coal had been placed directly on the fire. For the best results with a coking plate, it should be so arranged that the fireman must move the coked coal into the firing grates at the proper time. Horizontal grate furnaces with a simple coking plate built in the front of the fire box are satisfactory for this stage of the burn. The advantage of this type of grate is that it gives a good clear fire when properly handled. The disadvantages are that it requires intelligent and close attention and that with some coals there is considerable clinkering.

Inclined grate furnaces are easy to handle since they work semi-automatically and clinkers are few and easily removed. However, as ordinarily built, they have a tendency to give smoky fires, for two reasons:

1. The gases given off do not come in contact with the hot coals but pass directly into the kiln.
2. The fuel is not thoroughly coked before it drops or is pushed down into the combustion zone.

The first difficulty may be avoided by building an arched roof slanting downward over the fire box. The second calls for fire boxes specially designed to meet the reqirements of the fuel being used. (See Hull. Trans. Am. Cer. Soc. Vol. VIII, page 284).

Changes During Oxidation. During this stage the porosity of the piece has decreased slightly; exterior volume has decreased somewhat; and the ware has become slightly harder. If the oxidation has been thorough, the ware will be uniform in color over its cross section; but if oxidation has not been completed, a dark spot will be found in the interior of a draw trial.

On the chemical side, all of the CO_2 has been expelled and also all of the carbon. If oxidation has been completed, practically all the sulphur will have been expelled, and all the iron will

have been converted to ferric oxide. If oxidation has been faulty, part of the sulphur will remain, and part of the iron will be in the ferrous state. Ferrous iron, not carbon, is the coloring principal in the black spots in clay wares. Prominent among the pieces not properly oxidized will be found those set damp in the kiln.

VITRIFICATION PERIOD.

This period extends from the time oxidation is stopped until the ware reaches the point where it contains very little pore space and yet retains its shape. If loss of shape occurs, the ware has passed from vitrification into fusion. The upper end of the vitrification period may occur at 1800° F., as in some limey clays, or it may occur at 3000°F., as in some fire clays.

The chemical reactions that take place in clays during this period are not well known. It will suffice at this time to say that kaolinite and other hydrous silicates are broken down into more simple compound, and the basic oxides form compounds with silica or silica and alumina.

Vitrification means that melting is taking place in the ware. In any fine grained mixture the first material to melt is not the one with the lowest melting point, but a mixture of minerals with a melting point lower than that of any individual mineral present. This is called the eutectic mixture, or easy melting mixture. As the temperature is raised, this mixture gradually takes more material into solution. The glass formed in the ware does not run into the pores, but tends to spread out in films around the grains of unfused matter. These films of molten glass exert a high surface tension and thus draw the particles of unfused material closer together, causing the fire shrinkage of clay wares. At the same time, the open pores are squeezed shut. In short, the ware becomes vitrified. While this shrinkage of exterior volume is taking place, the volume of the actual material in the brick is increasing due to the fact that most materials swell when they melt. This is the highest point to which the heat treatment should be carried. If this point is exceeded, so much glass may be formed that the ware deforms and starts to fuse. In fact, with some clays, notably limey clays, the heat range between vitrification and deformation is so short that it is not safe to attempt to vitrify the wares at all.

Now, if oxidation was not properly conducted and any carbon dioxide, carbon or sulphur was left in the clay, swelling will take place as vitrification progresses. Except in cases of gross mismanagement, no carbon dioxide or carbon will be left in clay wares when vitrification begins. On the other hand, even when considerable care is taken during oxidation, sulphur will be present in many clays when vitrification takes place. It

may be present as FeS or FeSO$_4$. The sulphur present as FeS may form SO$_2$ gas by robbing some ferric oxide of part of its oxygen. The SO$_3$ in FeSO$_4$ may be replaced by SiO$_2$, which is a much stronger acid radical in molten magmas than SO$_3$. The formation of either of these gases in a vitrifying piece of ware can have only one result. The piece of ware bloats or swells. This bloating takes place whenever the gas is generated, in a dense piece of ware whether there is a black core in the piece of ware or not. It was at one time thought that the black core had something to do with the bloating. The only connection is that the black core indicates that oxidation has not been complete, and therefore black-cored ware is more liable to contain sulphur and to swell when vitrification ensues. This is really the basis for the rather wide-spread belief that ferrous iron is a decidedly stronger flux than ferric iron.

Aside from the tendency for the black core of a piece of clayware to retain sulphur, it has a detrimental effect on the strength of the ware. All clay wares expand when heated and contract when cooled. The rate of expansion varies with the physical and chemical condition of the ware. The rate of expansion, commonly called coefficient of expansion, of a black core is not the same as that of its surrounding red covering. The consequence is that as the ware contracts cooling strains are set up, which tend to form minute cracks and to weaken the place. It is a matter of common knowledge that black-cored or black-skinned paving brick do not stand the rattler test well and that black-cored or black-skinned pipe do not stand weather well.

Heat Treatment. As soon as oxidation is complete, as will be shown by the disappearance of any sign of a black core in a draw trial and the absence of blue sulphur smoke, the temperature may be raised rapidly to the finishing point and then held there until the heat has become uniformly distributed through the kiln.

The kind of flame used during the finishing or vitrification period will depend on the color of ware desired. If a clear red is wanted, enough excess air must be used to keep smoke out of the kiln. Fifty per cent will be enough if the fires are carefully handled. If darker colored wares are desired, a smoky flame may be used. In regions where dark colored ware have the most ready sale, some manufacturers have found that they can produce such ware by using an excessively smoky flame during the last three to ten hours of the burn. The ware is really no stronger, but it looks harder burned and stronger.

The production of dark faced rough texture brick has several advantages for the clayworkers of Iowa, since so many of our clays are rather off color for good reds and so many of them scum in drying and burning. The advantages are as follows:—

1. Clays which burn to muddy buffs or poor reds in oxidizing fires can be made to give artistic browns, dark reds and dark blues in rough texture effects. As far as color is concerned almost any clay can be used.
2. Scum is not nearly so noticeable on rough texture faces.
3. The smoky flame used at the finish of the burn tends to cause the scum to break up and disappear. Part of it is volatilized and part is melted into the brick. The absence of scum from flashed brick is well known.
4. It is easier to get good hard ware in the bottom of the kilns, due to the fact that a smoky flame is a long flame and reaches to the bottom of the kiln. In fact, for this reason the finishing period of the burn can often be cut down five or six hours.

For methods of producing the various effects in dark colored wares, reference is made to an article by W. A. Hull entitled "The Burning of Rough Texture Shale Brick"., (Trans. Am. Cer. Soc. Vol. XVI, p. 179).

AIR EXCESS NEEDED FOR BURNING.

Much has been written about the loss of heat due to the use of excess air in the firing of clay wares. With the use of solid fuel for any purpose it is necessary to have about 50% excess air on account of the difficulty of securing proper contact between the oxygen of the air and the fuel to be burned. The only two stages of the burn in which the excess air need exceed 50% are the watersmoking period and the oxidation period.

During the watersmoking period, eight to twelve times as much air will be used as is necessary for the combustion of the fuel employed. However, the actual cost of the use of this enormous excess of air is really small because (1) the amount of fuel used is quite small, and (2) the gases do not leave the kiln at temperatures much above that of the incoming air. The total heat carried out by the waste gases during watersmoking of a kiln containing a hundred tons of dry ware will amount to about 1000 pounds of coal, and only part of this is chargeable to excess air.

As far as the clay is concerned, there is no need for excess air during chemical dehydration. With suitable fire boxes and proper firing, the excess air need not be large from the time that watersmoking ends until oxidation begins. Since the temperature of the waste gases are still not high, the loss from excess air is not excessive.

During the oxidation period, we need excess air, but it is difficult to maintain temperatures around 1600°F., with a large excess. Bleininger reports, in the Trans. Am. Cer. Soc. Vol. X.

the heat distribution of four kilns. By actual analysis, he found that at this period only about 35% to 60% of the flue gases consisted of air. In other words, the kilns were using from 53% to 150% excess air. An average figure would be 100%. During the finishing period air excess need not be over 50% at any time. By calculation from the data presented by Bleininger, we find that the losses of fuel due to an air excess above 50% were as follows for the complete burn:

Sewer Pipe Kiln	Paving Brick Kiln	Terra Cotta Kiln A	Terra Cotta Kiln B
3.4%	1.6%	5.7%	24.8%

The figures for the paving brick kiln are too low for economy. In the case of this kiln the air excess was cut down to 50% just when the kiln was entering the oxidation period. The result was that it was four and one-half days in passing through this period. It would have paid better to have used more air and spent less time on the oxidation.

The figure for the last kiln is much too high. This kiln also was mismanaged in that entirely too much air was admitted during the chemical dehydration and finishing periods, the very times at which it was not needed. In this way 6½ tons of coal, or 16% of the amount used in burning the kiln, were wasted. In fact, an additional loss was incurred due to unnecessary prolongation of the burn. If we deduct this apparent waste, the loss due to excessive air for the kiln would be 24%—16%=8%; and this could have been cut down without injury to the ware by using a little less air in the other periods of the burn.

We may conclude that the only two periods of the burn during which an excessive amount of air is necessary are the watersmoking and oxidation periods and that the loss from excessive air should be not less than 3% nor more than 8%. With poor management, the loss due to this cause may amount to 25% of the fuel used without any improvement in the ware.

RADIATION LOSSES.

The big cause of loss of heat in periodic kilns is due to radiation.

From Bleininger's data has been calculated the following heat distribution in open kilns burning three classes of ware:

	Sewer Pipe	Paving Brick	Building Brick
Heat taken up by ware	5.7	11.3	19.55
Heat taken up by kiln	5.7	5.6	9.77
Heat lost due to unburned fuel in ashes	4.6	3.9	3.51
Heat loss due to air above 50% excess	3.4	1.6	3.03

Heat loss due to gases leaving

kiln hot	15.2	28.3	24.30
Lost by radiation	65.3	49.3	40.00

Building Better Kilns. Considerable could be done toward lessening the radiation from periodic kilns by building thicker walls and crowns and using better heat insulating materials. Although it is not generally recognized ,the great saving in fuel accomplished in the substitution of continuous kilns in place of periodic kilns is due, in large part, to the smaller amount of radiating surface per unit of ware and to the heavier construction of the continuous kilns. In fact, if continuous kilns saved all the fuel used in periodic kilns in other ways, but lost as much by radiation as do the periodic, they could not show the efficiency they do. It is on account of this difference in radiation losses between the two types of structures that attempts to apply the continuous system of burning to a group of periodic kilns by connecting them up by a system of flues or pipes, have not been as successful as might be anticipated. In this condition it is believed that a steel shell for a kiln is a good thing. It will hold the kiln in shape and prevent cold air from leaking in at cracks. However, care should be taken to see that the insulating qualities of the wall are at least equal to those of an ordinary kiln wall.

Of course, the larger part of the radiation from kilns comes from the crowns. It would pay brick makers to investigate means of insulating these. In this country, crown coverings for periodic kilns are either absent or very light. In Europe they are made at least a foot thick. The covering should make a fairly good insulator, and be light and resistant to wind and rain. Ashes have been used, but they blow about in windy weather and wash badly in heavy rains, besides soaking up all the water that falls on them. A mixture of ashes and clay has been suggested and also the use of hollow tile. Probably the most satisfactory material would be very porous bricks or slabs. Such brick are on the market, but it should be possible for a brickmaker to manufacture material for himself. In all cases, the covering should be coated with a cement wash to make it waterproof.

Shortening the Burn. The second means of saving radiation losses is by shortening the burn especially at the high fire period. This means that we must be able to raise the heat rapidly when we want to, which requires plenty of draft and plenty of grate area. Lovejoy[*] claims that the tendency in this country is to build kilns with too small grate area, and recommends that the grate area for kilns to be burned at cone 1 should be $1\frac{1}{2}\%$

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[*]Brickyard Economics

of the cubical contents of the kiln. In terms of fire boxes this would be about as follows:—

Diameter of kiln	20 ft.	24 ft.	28 ft.
Grate area	33 sq. ft.	47 sq. ft.	65 sq. ft.
Number of fire boxes	10	10	12
Size of grate	14"x36"	15"x42"	15"x52"

For higher cones more grate area should be provided. When the grate area is too small, it is very difficult to raise the temperature and the kiln lags along, using up coal and heating up the surrounding atmosphere. In fact, it is perfectly obvious that if the grate area were too restricted we would reach a point at which we could keep on firing indefinitely without raising the temperature of the kiln. In all cases of restricted grate area, we tend to approach this condition.

CONCLUSION.

With a given kiln and fuel, the shortest and most economical firing can be accomplished by following the program given below.

1. Set only dry ware in the kiln.
2. Watersmoking—300° F. Use a strong draft and an abundance of air.
3. Chemical dehydration 300°.—best oxidation temperature, 1400° F.—1650° F. Raise temperature as rapidly as possible cutting off all air except what is necessary to prevent ''slabbing.''
4. Oxidation, 1400° F.—1650° F. Maintain a bright, clear fire at as high a temperature as possible without starting to vitrify the clay. All smoke retards the burn.
5. Vitrification, 1400° F.—1650° F.—finish. Raise the temperature as fast as can be done fairly uniformly, using only as much air as will give desired color to ware, and then allow kiln to soak until the heat evens up.

BULLETINS OF THE ENGINEERING EXPERIMENT STATION

†Not yet available for distribution.
*Out of Print.

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The Graduate Division conducts advanced research and instruction in all these five lines.

Four, five and six year collegiate courses are offered in different divisions of the College. Non-collegiate courses are offered in agriculture, engineering and home economics. Summer Sessions include graduate, collegiate and non-collegiate work. Short courses are offered in the winter.

Extension courses are conducted at various points throughout the state.

Research work is conducted in the Agricultural and Engineering Experiment Stations and in the Veterinary Research Laboratory.

Special announcements of the different branches of the work are supplied, free of charge, on application. The general catalogue will be sent on request.

Address The Registrar,

Ames, Iowa.