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EXPERIMENTS IN THE RAPID DRYING OF PLASTIC CLAY BRICK

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ABSTRACT

In some types of plants the rapid drying of clay products is desirable. Experimental drying of face brick made from a plastic fire clay indicated that in these cases conventional methods required far too much time. At an ambient drier temperature of 300° F., or higher, and in an atmosphere containing a higher percentage of water vapor, face brick were dried successfully in one-half to one-third the time required with other methods.

INTRODUCTION

Purpose of the Investigation

In the conventional type of brick plant where the ware is fired in periodic kilns the time consumed in drying is of minor importance, although the original investment in drier capacity and drier cars is increased in proportion to the time required for drying. In plants using a combination drier-tunnel kiln it is important, however, that the drying time be reduced to a minimum because the ware is set on the kiln cars from the off-bearing belt. Because these cars must go through the drier the number of highly expensive kiln cars required may be greatly increased, especially if the clay permits rapid firing of the brick.

The first objective of this investigation was to determine the length of time required by conventional methods to dry the plastic fire clay face brick selected for testing. The second objective was to find some means of decreasing, as compared to conventional methods, the time required for drying.

Published Information on Drying

Although the literature on the drying of clay ware is rather extensive the bulk of the material has been published in periodicals such as the Journal of the American Ceramic Society, Transactions of the British Ceramic Society, Transactions of the Ceramic Society (English), Journal of the Canadian Ceramic Society, and Industrial and Engineering Chemistry. The few books commonly cited as references on this subject include Greaves-Walker (1948), Lovejoy (1927), and Wilson (1927). In addition to the above we have found a great deal of helpful information on drying in Norton (1949, 1952) and McNamara (1939).

The literature on this subject covers the field very thoroughly, including discussions of the fundamental principles of drying, drier design and calculations on design and heating, drier construction and operation, and the drying characteristics of clays. Very little of the literature on drying includes reports on experimental drying (Morgan and Hursh, 1939; Norton, 1949), and we were able to find but one reference to the drying of clay ware at temperatures above 212° F.

Anwyl (1951) states that in two types of periodic driers employing vertical movement of heated air, temperatures higher than 212°F. were used. In the first type no fans were used and air was brought through small ducts to the floor of the drier tunnel about 6 feet below the car deck. On page 42 he states: "Heat was supplied by small fires on the floor level, and air flow was induced by rise of the hot products of combustion of the fires, thus heating the ware by convection. The moisture and other products of combustion escaped from the unit through vents in the roof . . ." Temperatures were "much above the boiling point of water."

The second type was similar to the first in that the air flow was vertical. Instead of slow-moving hot air from a fire, however, high velocity heated air was used. Temperatures in excess of 300° F. were used at the beginning of the drying cycle. Anwyl does not mention the humidity of the air in the driers, but one would judge that the humidity would have to be rather high to permit drying at those temperatures.

Acknowledgments

We wish to express our appreciation to T. J. Orrender, President of the Salina Brick and Tile Company, for his cooperation in furnishing us a large supply of face brick for the drying tests.

TESTING

Analysis of the Problem

The drying of clay ware is accomplished by the evaporation of water from the surface of the ware. Most of the water evaporated from the piece of ware must come from the interior through interconnecting pores or channels. The rate of this internal flow of water is determined by the moisture gradient between the wetter and drier portions, the permeability of the ware, and the viscosity of the water. We can increase the moisture gradient by increasing the flow of dry air around the surface of the piece. The permeability can be increased by adding coarser materials to the ware, such as sand or grog. The viscosity of the water can be decreased by working at a higher temperature.

If the moisture gradient is increased beyond a certain point cracking or rupture of the ware will result from differences in shrinkage within the ware. In most cases increasing the permeability is not desirable both because of the changed appearance of the finished ware and increased cost. Working at higher temperatures to decrease the viscosity of the water seems to offer a promising approach to increasing the rate of drying. If, however, dry air at a high temperature is used for drying, the moisture gradient will be increased, with resulting cracked or ruptured ware. If the rate of evaporation from the surface could be decreased at the same time the temperature is increased the moisture gradient would be reduced, and at the same time the rate of drying increased due to the lowered viscosity of water.

Increasing the humidity of the surrounding air will reduce surface evaporation on the ware and eliminate cracking. Most modern drying systems include humidity control as an essential feature. The commonest form of drier used in the brick industry is a tunnel through which the ware passes on drier cars. The air movement is from the dry end to the wet end of the drier. Thus the nearly dried brick receive the hottest and driest air. The temperature of the air decreases toward the wet, or entrance end of the drier, and the humidity increases in the same direction due to moisture picked up from the bricks in the drying process. Thus the surface of the wet brick near the entrance of the drier is kept moist and the moisture gradient reduced. As the interiors of the brick become drier they are able to withstand the higher temperatures and lower humidity near the exit end of the drier. Periodic driers operate on the same principle, but moisture must be added to the air by artificial means at the beginning of the drying cycle. Temperatures commonly employed in drying brick range from about 120° F. at the beginning of the drying cycle to 180° F. at the end. These temperatures are relatively low.

Drying of clay ware can be divided into three well-defined stages. The water added to the clay to produce a plastic mass must be removed first. During the first stages of water removal the clay ware shrinks in direct proportion to the volume of water removed. In ceramic terminology this is shrinkage water. After the shrinkage water is removed the remaining water retained in the cavities between the clay particles is called the pore water. Shrinkage water is difficult to remove rapidly because a moisture gradient produces differential shrinkage. The surface of the piece will be much drier than the interior and will shrink a greater amount, resulting in cracking near the surface. Differences in the amount of moisture from one end or side of the piece to the other also produce warping. The pore water can be removed with relative ease both because of increased permeability and lack of differential shrinkage.

In most clay drying processes the third stage of water removal is carried out in the kilns. Clays dried at 212° F. will retain some moisture as hygroscopic water which can be removed at a temperature of 280°F. or higher. Clays heated to 300°F. are usually free of hygroscopic moisture. Although the amount of water so retained is small it is sufficient to cause rupture of ceramic ware heated too rapidly. In a continuous drier-tunnel kiln process, drying and pre-heating, or initial stages of firing, must be considered as a whole. Clay dried in a periodic drier to 300° F. and allowed to cool before setting in the kiln would regain most of the hygroscopic moisture. Therefore, the pre-heating from 212° to 300° F. must be carried out in the kiln.

The clay used for the drying tests reported here is a plastic fire clay from the Terra Cotta member of the Dakota formation. The deposit is described by Plummer and Romary (1947) under the location number TC-1. The clay is mined by the Salina Brick and Tile Company from a deposit in the SE¼ sec. 14, T. 15 S., R. 6 W., Ellsworth County. It is a "tight" or "fat" clay of the type that usually requires slow drying.

Differential thermal analysis of this clay (Fig. 1) indicates that the chief clay constituent is kaolinite, but minor endothermic inflections at 700° C. and 900° C. are probably indicative of montmorillonite and illite, and possibly a mixed-layer type of clay mineral. Either of these clay minerals would increase the plasticity and water retention of the clays. The differential thermal analysis on this clay was run on the wet material taken from a brick just as it came from the off-bearing belt. The endothermic peak near 100° C. is therefore abnormally large. The hygroscopic moisture peak slightly above 150° C. is quite small but

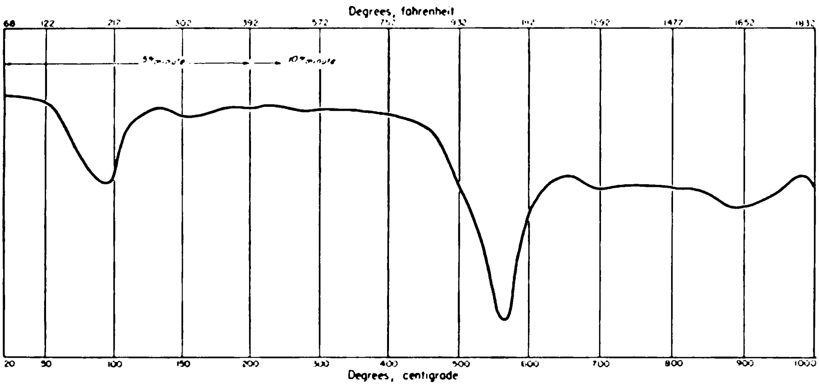

FIG. 1.—Differential thermal curve of buff-firing clay from which test bricks were made.

normal in size. The peak extends to about 180° C. because of the rapid rate of drying and possibly because of higher temperature water given off by illite or montmorillonite. These curves indicate that the greater part of the water is removed between the temperatures of 50° C. (122° F.) and 100° C. (212° F.), and that a minor amount is removed slightly above and below 150° C. (302° F.).

On consideration of the above factors we concluded that rapid drying of the TC-1 clay could be accomplished only by a combination of high temperature and high humidity.

METHODS AND EQUIPMENT USED IN TESTING

The brick used for the drying test were full-sized, cored face brick with a textured surface on one side and both ends. The wet bricks were taken directly from the off-bearing belt, wrapped in oil paper, and packed closely in a box to prevent drying before being shipped to the ceramics laboratory of the State Geological Survey. Most of the bricks tested were buff-firing, but a few more plastic red-firing bricks were also included.

In the tests the brick were set in courses of 10 brick each, and in two to four courses. The spacing of the brick was similar to that used in placing brick on a plant drying car. In the final tests three courses, or a total of 30 brick were used for each batch.

The first drying test was attempted in an electrically heated drier with a thermostatic control. Due to the heavy load of bricks the temperature dropped from the normally maintained 212° F. to about 130°F. immediately after placing the bricks in the drier. The temperature increased very slowly, and after a 24-hour interval was at 160° F. For the next 6 hours the temperature increased more rapidly to 180° F., but the bricks were obviously damp in protected spots after a total drying time of 30 hours. The drying process was slowed by the fact that all but the lower part of the pile of bricks was enclosed in oil paper during the first 8 hours of the drying. This was done to keep a humid atmosphere around the bricks.

All subsequent tests were conducted in a Denver Fire Clay Company gas-fired muffle kiln having a capacity of 12 cubic feet. The kiln is the fire tube muffle type. In the drying tests the three front tubes were removed, thus permitting the escape of moist air through the crown. The kiln floor and crown are not completely gas tight; therefore if the dampers were partially closed some of the gases from combustion entered the ware chamber.

The test bricks were set on a single course of fired bricks, which in turn was placed on a thin silicon carbide slab supported so that heat was free to circulate beneath it (Fig. 2). A thermocouple was placed near the test bricks to record the temperature of the drier atmosphere. Another thermocouple was placed inside a brick located in the center of the middle course. The hole through which the thermocouple leads entered was carefully plugged with wet clay.

During the first series of tests in this drier-kiln we were unable to determine how far the drying had proceeded at any stage of the process. To correct this testing defect the bricks were placed on a balance with the beam extending through a built-up kiln door. The assembly was carefully balanced before the beginning of the drying process, and as water was lost weights were removed from the outside end of the balance beam. Some error in weighing was produced by the lengthening of the hot end of the beam, and by the difference in specific gravity of the atmosphere within the drier and outside. Some attempt was made to compensate for these errors, but the temperature-weight loss curves indicate that an appreciable error remained (Figs. 3-7).

Throughout most of the tests a humid atmosphere was maintained in the drier by running a thin stream of water into a shallow pan placed near the hot drier floor. This pan was drained

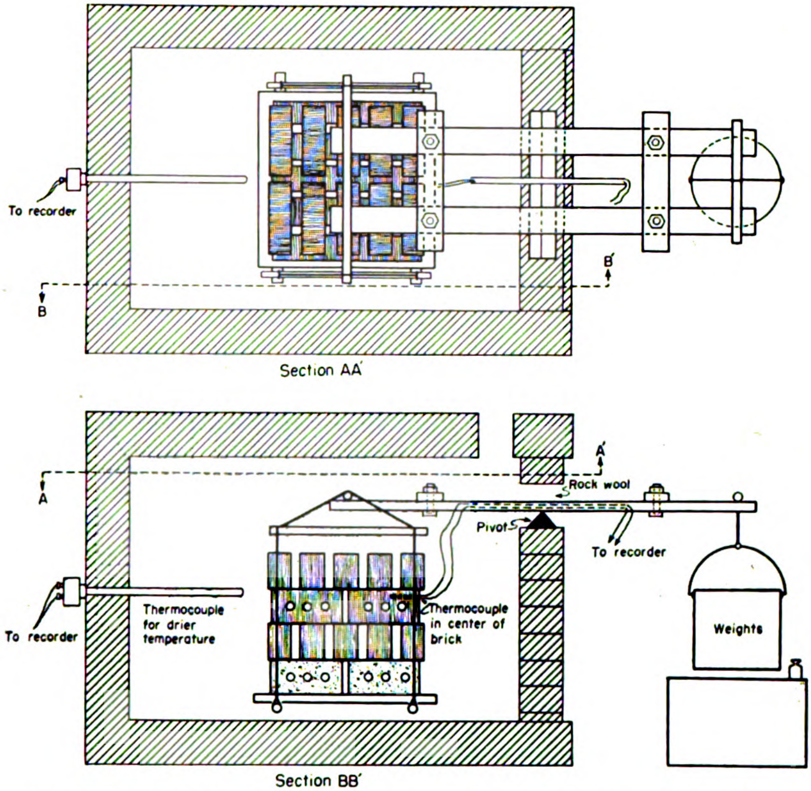

FIG. 2.—Sectional views of drier used in tests, showing method of supporting test bricks on a balance.

by a copper tube to the outside of the drier so water in excess of that vaporized by the heat did not accumulate in the pan. During the earlier stages of the drying enough water was run into the pan so that a slow drip was maintained from the drain tube. This provided a rough control of humidity within the drier inasmuch as more water vapor was provided with increasing temperatures. This device is not shown in Figure 2.

Some means of determining humidity within the drier would be highly desirable. All the commonly employed devices can be used only at temperatures below 212° F., however, and would have been useless in conducting higher temperature drying tests. In fact, at temperatures above 212° F., and at atmospheric pressure, the amount of water vapor held in the drying atmosphere should be expressed as percentage of super-heated steam rather than as humidity.

Data on Drying Tests

In addition to the attempted drying test in our electric drier, seven tests were run in the kiln-drier previously described. In drying test No. 1 (Fig. 3) an attempt was made to dry the bricks

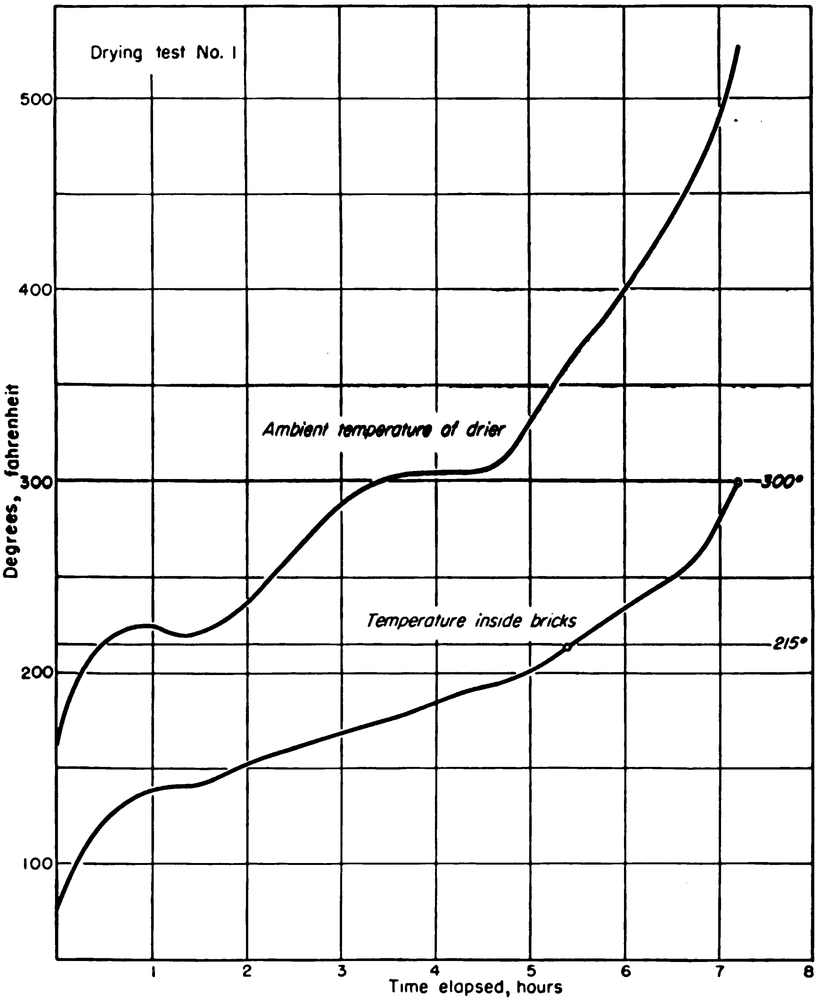

Fig. 3.—Graph showing temperature curves for drying test No. 1.

in less than 8 hours in a moderately humid atmosphere. A temperature of 215° F. was reached in 5.5 hours when several of the bricks were partially broken. At the end of the cycle most of the bricks were broken.

Throughout the drying tests a temperature of 215° F. has been considered the end-point of a normal drying time, rather than 212°, to allow for instrumental error (Figs. 3-9). Actually the error in some cases was much greater than this, as will be pointed out in subsequent paragraphs.

The drying time for test No. 2 (Fig. 4) was lengthened to almost 11 hours. After approximately 5 hours of drying, a previously weighed and marked brick was taken out and weighed, indicating that 50 percent of the water had been taken out. After a little more than 8 hours 75 percent of the water had been dried from the brick. At the end of the drying cycle the marked brick was broken in several pieces but another brick was weighed and returned to the drier. Twelve hours later the same brick was taken out of the still warm drier and found to be appreciably

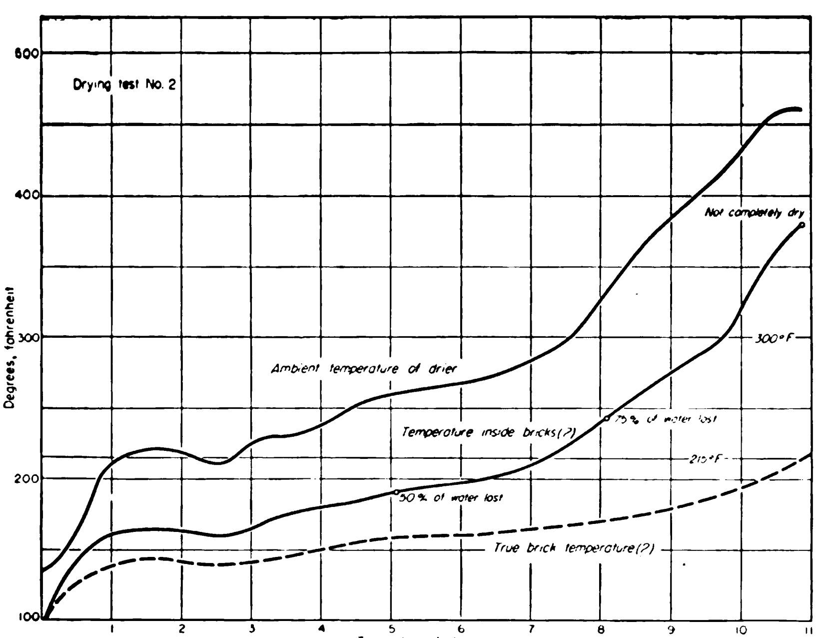

Fig. 4.—Graph showing temperature curves for drying test No. 2.

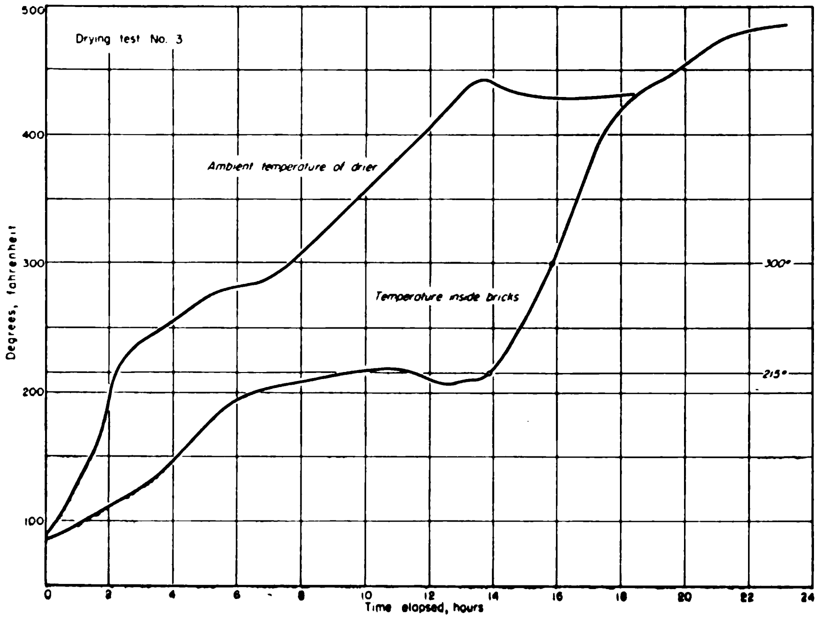

FIG. 5.—Graph showing temperature curves for drying test No. 3.

lighter. Inasmuch as this brick was not dry after nearly 11 hours, we concluded that the inside brick temperature recorded must have been much higher than the average of the bricks. The estimated temperature inside the bricks is indicated by a dotted line in Figure 4. Only 2 of the 30 bricks remained entirely undamaged by this drying test.

In drying test No. 3 (Fig. 5) the rate of heating was decreased and the humidity increased somewhat. No attempt was made to weigh the bricks on this test so drying may have been completed before the end of the heating cycle. We believe, however that the curve plotted for the temperature inside the one test brick indicates that all the tempering water was removed after 11 hours of drying by the rapid upward swing at that point. Most of the bricks were sound at the completion of this test.

At this point in the investigation we concluded that it would be necessary to weigh the bricks during the drying process in order to regulate the heat input and to enable us to determine the completion of drying. Subsequent test batches were there-

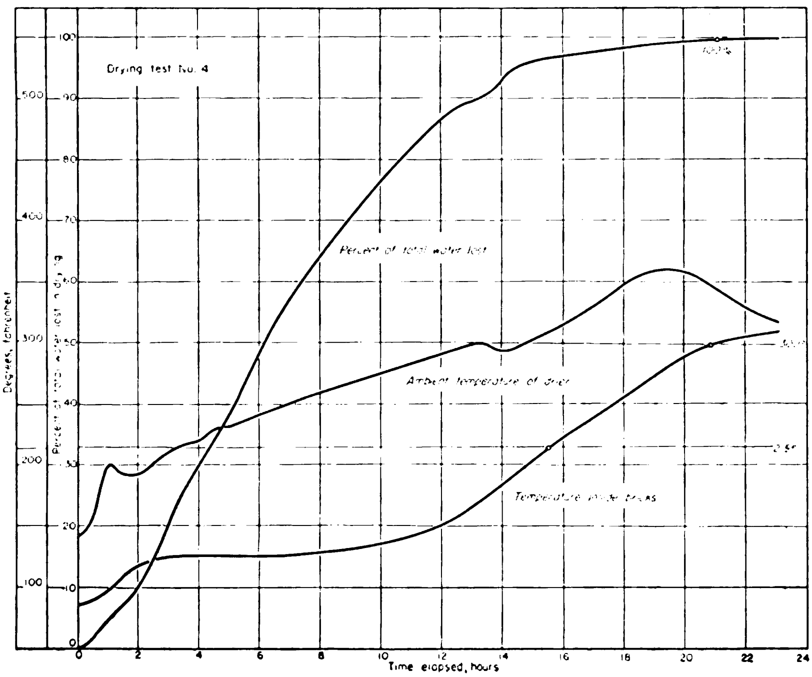

Fig. 6.—Graph showing temperature and water loss curves for drying test No. 4.

fore weighed throughout the drying cycle by the device shown in Figure 2.

With drying test No. 4 (Fig. 6) the temperature of the drier atmosphere was increased more slowly than in previous tests, and an attempt was made to keep the humidity somewhat higher. The temperature inside the brick containing the thermocouple reached 215° after 14.75 hours and 97.7 percent of the tempering water had been dried from the 30 bricks. Under ordinary plant conditions the bricks at this stage would have been considered completely dry. According to the temperature-water loss curves the last of the hygroscopic moisture was removed after 20.5 hours, corresponding to a brick temperature a few degrees above 300° F. The test bricks were dried without breaking or warping, but the time consumed in drying was not at the minimum of 8 hours that we hoped to attain.

For drying test No. 5 (Fig. 7) the drier temperature was increased as rapidly as possible to 300° F. and the humidity was in-

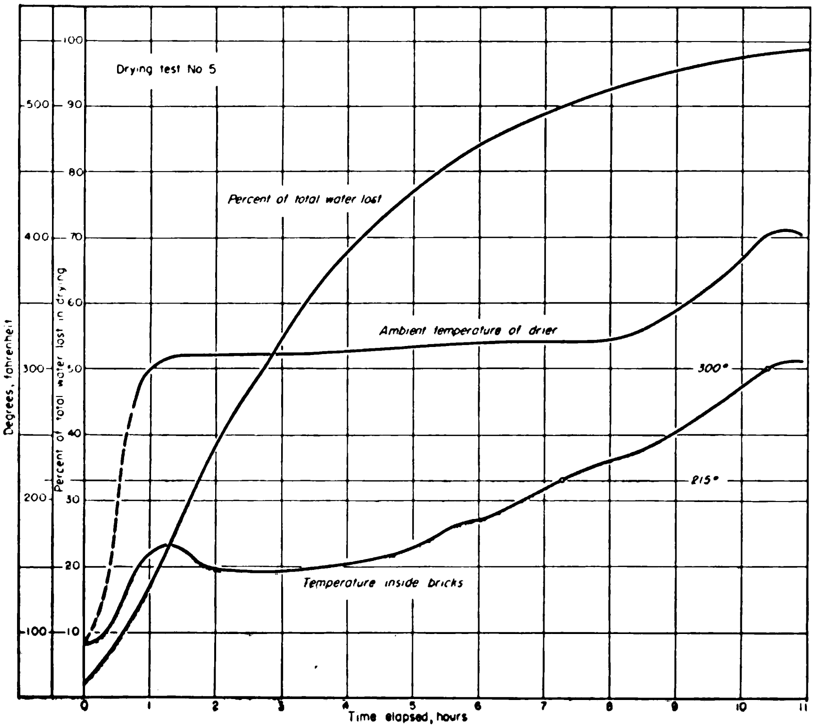

FIG. 7.—Graph showing temperature and water loss curves for drying test No. 5.

creased to near saturation at the beginning of the drying cycle. The high humidity was attained in a rather unconventional manner by nearly closing the flue damper to the drier, thus adding the water resulting from the combustion of natural gas to that provided by the drip pan. The water content of the drier atmosphere was so high that water condensed and dripped from all small openings to the outside of the drier. The temperature of the drier was increased to 300°F. in 1 hour, to 320° in a total of 8 hours, and then increased rapidly to obtain a temperature of 400° at the end of 11 hours. According to the instrument readings the temperature inside the bricks attained 215° after 7.15 hours, although weighing indicated that only 90 percent of the tempering water had been lost, and at the end of the cycle that 98 percent had been driven out. It is obvious that either the temperature inside the one brick containing the thermocouple was higher than the average, or that the weighing device was not accurate. It was

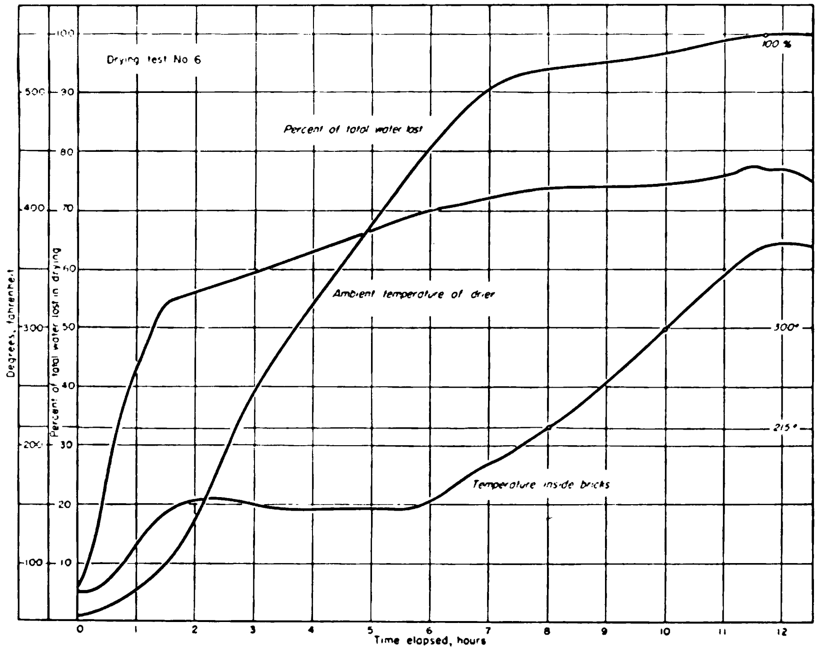

Fig. 8.—Graph showing temperature and water loss curves for drying test No. 6.

clear, however, that a means of rapid drying has been found. If the beginning temperatures for drying are considered as 300° for the drier and 120° F. for the brick the apparent drying time was about 7 hours for 212° dryness, or 9.5 hours for 300° dryness. Two of the 30 bricks were cracked.

During drying test No. 6 (Fig. 8) an attempt was made to obtain brick weights and temperatures inside the bricks that were more nearly correct. High humidity (or more correctly, a high percentage of super-heated steam) was maintained during a longer period of drying, and temperature differences between drier and bricks were greater. The recorded temperature inside the bricks attained 215° after a total of 8 hours drying, or 7 hours after the brick had reached a temperature of 115° and the drier 255° F. A temperature of 300° was attained in 9 to 10 hours, but, according to the balance weighing, complete dryness was reached after 10.75 to 11.75 hours. We believe that in this case the weighing was in error due to differences of specific gravity of the atmosphere inside the drier and the outside air and expansion of the

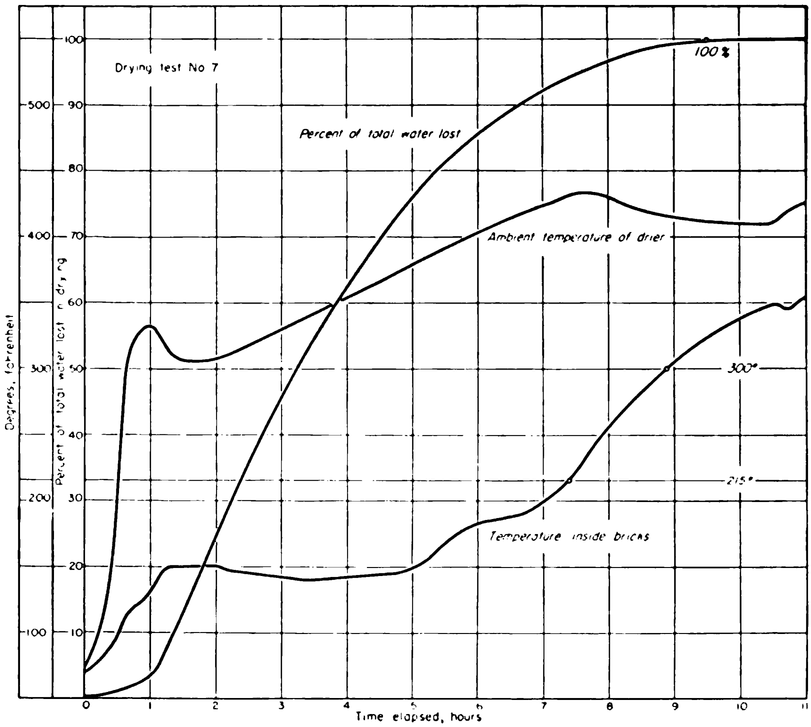

FIG. 9.—Graph showing temperature and water loss curves for drying test No. 7.

hot end of the balance arm. All the dried bricks were completely sound.

Drying test No. 7 (Fig. 9) was conducted with even greater care than test No. 6, and the drier temperature brought to 300° F. as nearly instantaneously as possible. Due to increased humidity (or percentage of super-heated steam) brick temperatures kept down to previous levels despite increased drier temperatures. After 7.4 hours total drying time the brick temperatures had reached 215° F., and a rapid increase in the slope of the brick temperature versus time indicates complete dryness despite the weight indication of 94 percent water loss. After 8.9 hours total drying time the brick had reached a temperature of 300° F., 99 percent water loss was indicated, and the drier temperature had dropped from a maximum of 440° F. to 415°. Complete dryness was indicated as occurring after 9.5 hours total drying time, or approximately 35 minutes after the brick had reached a temperature of 300° F. If drying is considered as beginning when the drier temperature reached 300° and the brick temperature 110° F. the tempering water was completely lost after 6.8 hours, and the hygroscopic water after 8.3 hours. Although this drying test included some red-firing bricks made from an even more plastic clay than that used for the manufacture of the buff-firing ones, none of the brick were cracked or warped in the drying process.

The inconsistencies found to occur between brick temperatures and percent of total water removed are due not only to inherent errors in the weighing mechanism, but also to the fact that the completely dried bricks were weighed after having reached temperatures well in excess of 300° F. Loss of water was calculated on the basis of the differences of the weight of

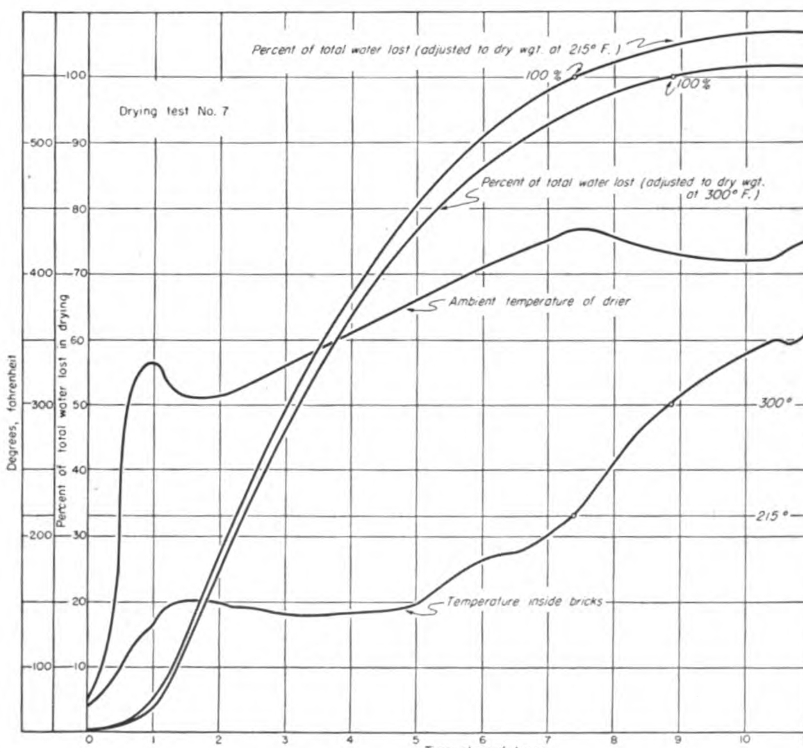

Fig. 10.—Graph showing temperature and adjusted water loss curves for drying test No. 7.

the bricks before drying and after having reached this high temperature. The color of the brick indicated that some oxidation of iron and organic materials had taken place. It is also probable that some higher temperature water was driven off. The differential thermal analysis curve (Fig. 1) indicates that an endothermic reaction did occur above 300° F. If these factors are correctly interpreted the water loss curves should be adjusted so that 100 percent dryness coincides with the 300° brick temperature if the drying plus preheating is considered the end point, or if 212° F. dryness is the purpose of the process the 100 percent dryness point should coincide with 212° F. temperature of the bricks (or 215° as used in these tests). Such an adjustment would have been made in all the curves if lower temperature points on the curve could have been correctly estimated. Adjustments to both end points have been made for drying test No. 7 and are shown in Figure 10.

SUMMARY AND CONCLUSIONS

The length of time required to dry brick made from a plastic clay can be shortened only by increasing temperatures, by increasing the movement of drying air, or a combination of both. Increase of drying temperatures was used in the drying tests described because laboratory facilities were best adapted to this procedure, and because increased air movement would also tend to increase surface drying in proportion to interior drying of the bricks. Increase of temperatures and an increased rate of temperature rise will also produce excessive surface drying at the expense of interior brick drying unless controlled by increasing humidity.

Eight drying tests indicate that a safe drying time of more than 24 hours required with conventional methods of drying can be shortened to less than 8 hours with drier temperatures in excess of 300° F. and with high humidity throughout most of the drying cycle. At temperatures above 212° F. the term "percentage of water vapor," or "percentage of super-heated steam" probably should be substituted for "humidity," although at or near the surface of the wet bricks the term "humidity" continues to apply.

Further tests should be conducted with this type of drying and with some improvements of the equipment used. Some means of measuring humidity, or percentage of water vapor in the atmosphere of a drier at temperatures above 212°F., is especially needed.

The type of drying described in this report would be most easily adaptable to the periodic type of drier if applied on a commercial scale. It is probable, however, that such drying could be carried out in a continuous tunnel-type drier if the heat were applied from the bottom of the drier and the air movement was vertical rather than horizontal. If a continuous drier were used, special precautions would have to be taken when additional loaded drier cars were placed in, or taken out of the drier. A vestibule at both ends of the drier may be required to prevent shock cooling or heating and rapid changes in the drying atmosphere. Such vestibules are found in some types of combination drier and tunnel kiln. With this combination it is especially important to avoid cooling the bricks at the end of the 300° drying temperature and the beginning of the kiln firing. It would be possible to dry to 212° F. with the method used in the tests and to carry out the pre-heating from 212° to 300° in the low temperature zone of the kiln. This method, however, would require additional time because humidity control is not feasible in the pre-heating zone of a tunnel kiln.

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