THE WATER SMOKING OF CLAYS¹

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ABSTRACT

Experimental Method.—The water smoking behaviors of two plastic brick clays, one shale and one fire-clay were studied by heating 4-in. cubes at different rates, two thermo-elements being buried in the brick and two others placed against the exterior surface.

Results of Conclusions.—To save time in water smoking, the ware should be previously dried not far from 100 °C, good circulation should be provided in the kiln and the temp. of the interior of the product should not lag appreciably behind that of the kiln. It should be possible to water smoke heavy clay products in 15 hours with heating rate of 20 °C per hour.

Introduction

The introduction of the tunnel kiln and the general necessity of cutting down the time consumed in burning make it desirable to study the water-smoking process in greater detail than has been done in previous work and to establish the minimum time required for the expulsion of the hygroscopic water. This involves also the study of the thermal changes taking place in clay and the establishing of the minimum temperature necessary to drive off this last portion of the mechanically held water. The work, in brief, consisted in following the temperature lag due to the presence of the residual water both with reference to the magnitude of the lag and its connection with any critical temperatures.

The materials studied were two plastic brick clays from the District of Columbia Workhouse, which are of an exceedingly tough structure and retain water very tenaciously; a shale from Milton, Pa., and one from the District Workhouse; and one fire-clay from Lester, Arkansas.

The plastic clays were chosen for this purpose owing to their exceedingly well developed plastic structure. Each sample was ground to pass the 20-mesh sieve, pugged thoroughly to a stiff plastic consistency and pressed by hand in molds to form

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four-inch cubes. Some of the specimens were previously dried to constant weight at 50°C before being subjected to the water-smoking treatment. Others were air-dried in the laboratory from one to five days at atmospheric temperature.

The water-smoking process itself was conducted in an electrically heated oven, the inside dimensions of which were $8 \times 8 \times 12$ inches. In each run the test piece was placed in the center of the furnace thus permitting free circulation of air on all faces of the cube. The furnace temperatures were read by means of copper-constantan thermo couples in contact with the upper and lower surfaces of the cube. A gentle current of air was provided for the removal of the steam. The temperatures within the cube were obtained from two thermo couples embedded within the piece at depths of one and two inches, respectively. All the temperature readings were recorded by means of a multiple point potentiometer. The maximum temperature to which the specimens were carried was 300°C. The duration of the water-smoking treatment was varied from three to eighteen hours.

Experimental

The results obtained are illustrated in the diagrams of figures Nos. 1 to 16, and these curves will be discussed in order in the following paragraphs:

Figure 1.—This specimen made from the plastic brick clay, as well as those immediately following, was dried to constant weight at 50°C previous to the water-smoking treatment. The furnace was brought to 300°C in three hours. It will be observed that beginning with room temperature the lag between the furnace temperature and that of the cube increases steadily, indicating increased heat absorption by the clay. This condition continues after the furnace has reached the maximum temperature. It is interesting to note that there was practically no lag between the points one inch distant within the cube, showing that the conductivity of the clay is very much greater than we should expect since even with this fast rate of heating there was such complete equalization. It is evident, however, that the rate of heating was entirely too fast.

Figure 2.—In this experiment we have the same clay, the

plastic material from the District Workhouse, and it will be observed that although the time of drying has been doubled the area of heat absorption does not tend to diminish appreciably, indicating that considerable heat work is being done in removing

FIG. 1

FIG. 2

the hygroscopic water and that the rate of heating is still so fast that there is a decided lag between the furnace and clay temperatures.

Figure 3.—Here again we have the same clay previously dried to 50°C but heated to 300°C in 12 hours. It will be observed that the temperature lag is nearly constant throughout the run and that the temperature of the cube coincides with the furnace temperature only after one hour's heating at 300°C . The inflections of the cube temperatures shown in the curves of

FIG. 3

figures 1 and 2 at approximately 80°C and 280°C have been smoothed out although there is some indication of the higher lag point.

Figure 4.—The material represented by this diagram is a soft shale which shows an even greater heat absorption than the clay previously discussed but gives indications of reaching thermal equilibrium somewhat more rapidly.

Figure 5.—This diagram again represents the plastic brick clay discussed above but with a water-smoking run of 15 hours. This rate of heating thus has removed the lag so apparent in the previous diagram, inasmuch as the temperatures of the clay followed the furnace temperature very closely, thus indicating

that the heat requirements of the clay at each particular point are met by the furnace with sufficient promptness. It is evident that such a condition of gradual and constant vaporization tends to carry through the process without undue strains due to the

FIG. 4

FIG. 5

temperature differences between the surface and the center of the cube. Such a condition is therefore very desirable in actual burning operations.

Figure 6.—This diagram represents another of the very plastic brick clays, studied with a high content of hygroscopic water,

FIG. 6

FIG. 7

approximately 4.4 per cent. Here again the duration of the run was 15 hours, but the high water content has been found to cause a distinct lag which persists up to the maximum temperature. The increasing lag between the two cube temperatures towards the end of the run would indicate decreased heat conductivity brought about by the drying out of the clay.

Figure 7.—These curves represent the heating up of the plastic silicious fire-clay containing one per cent of hygroscopic water. It is observed that there is only a slight lag between the tempera-

FIG. 8

tures of the furnace and of the clay specimen, indicating that this rate of heating provided all the thermal energy required for water smoking without any appreciable temperature difference within the cube. The heat treatment, therefore, is entirely normal and satisfactory.

Figure 8.—Representing the same fire-clay but with a slightly higher content of hygroscopic water, this diagram is of interest inasmuch as it indicates the temperature limits between 100 and 250°C.

It was then decided to determine the temperature range between which the process of water smoking takes place and at the same time fix the critical temperatures involved with greater cer-

tainty. It was evident from the previous work that clays previously dried to 50°C would not show these facts with sufficient emphasis, owing to the low content of hygroscopic water. For this reason it was decided to use the clays in the air dried state, after drying from one to five days at atmospheric temperature. In several cases the air drying was carried to constant weight, which required a week or longer.

Figure 9.—This diagram represents the brick clay No. 1, dried four and a half days at room temperature. The rate of water smoking was very rapid and in fact too rapid to show the

FIG. 9

critical temperature involved with sufficient accuracy. It is evident that owing to the rapid rate of heating these temperatures are displaced upwards and equilibrium between the furnace and the specimens is not attained until after prolonged heating at 300°C . As should be expected, due to the relatively high water content, the heat absorption area between the furnace curve and the clay curve is very large. There is likewise a considerable lag between the two points within the cube. From the appearance of the curves it is evident that considerable pore water is still present in the clay, since the thermal lag is apparent

from the very beginning of the heating. It would seem, however, from the configuration of the curves that the typical water-smoking temperature range lies between 100°C and some point below 300°C . For this reason it was decided to subject the same clay

FIG. 10

FIG. 11

specimen, dried only two days, to a less rapid heat treatment, taking nine hours to reach 300°C.

Figure 10.—Here brick clay No. 1 still containing about 28 per cent of water shows the thermal lag to lie between 100 and 240°C, which gives us the desired information for a case of this kind.

FIG. 12

FIG. 13

Figure 11.—In this case we are dealing with brick clay No. 2 which is of the same type as No. 1 and which still contains 35.6 per cent of water. The heat absorption again, neglecting the pore water proper, is included between 100 and 240°C.

Figure 12.—This diagram represents a brick clay dried at atmospheric temperature to constant weight and then subjected to a water-smoking treatment of nine hours. The lower heat absorption limit is found to be above 100°C and the upper one at approximately 250°C.

Figure 13.—This diagram represents again brick clay No. 3, previously air dried to constant weight and still containing 3.8

FIG. 14

per cent of water, the rate of heating being slowed down and the heat treatment extended to 12 hours. Here the temperature lag is included between 100° and approximately 240°C, and it would seem that this point is independent of any previous drying treatment to which the clay has been subjected. Since the lag between the furnace and the clay temperature is not excessive and hence not likely to cause inordinate strains, it appears that 12 hours time is required to expel the hygroscopic water.

Figure 14.—In this diagram we have the plastic fire-clay with a water content of 9 per cent at the beginning of the water smoking.

From this greater content of water it would appear that there must be considerable lag between the furnace temperature and that of the cube as well as between the two points within the latter. Owing to the presence of pore water the heat absorption must obviously extend to a point below 100°C , while the heat absorption due to the hygroscopic water is again included between 100 and 240°C .

Figure 15.—In this diagram and the one following, extreme cases were taken in which the air drying was conducted only through one day and through a half day, respectively. In the

FIG. 15

present case (brick clay No. 1) the material still contained 18.7 per cent of water. The heating was conducted at quite a slow rate, covering 18 hours. It is evident that in this case there is considerable overlapping in the expulsion of the pore and hygroscopic water since the former could not be completely driven off in the time allowed before reaching 100°C . The thermal lag, therefore, is very large and the test specimen must necessarily have been subjected to a decided strain. However, the critical temperatures are again, as indicated before, between 100 and approximately 240°C . It is interesting to note that even under these conditions the water smoking was completed in about $13\frac{1}{2}$ hours.

Figure 16.—In this diagram we again have the silicious fire-clay but air dried only for one day with the result that the temperature lag and the area of heat absorption are very marked. Overlapping of the evaporation of pore and hygroscopic water again occurs and there is a decided drop in temperature between

FIG. 16

FIG. 17

the surface and the interior of the test piece, a condition which is obviously objectionable but would not have occurred if the clay had been previously dried sufficiently.

Conclusions.—From this work the following conclusions may be drawn:

For the purpose of expediting the water smoking of clay products, it is necessary to dry the ware thoroughly and as close to 100°C as possible, a statement which agrees with practical experience. It is also obvious that the permissible rate of drying is a function of the surface of the product referred to unit volume. In other words, thin ware can be dried very much more rapidly than products of heavy cross section. The four-inch cubes employed in this study are comparable with the heavier clay products such as bricks.

It is necessary, in water smoking as rapidly as possible, that the steam which is produced be removed promptly. In practice a great deal of time is lost due to the poor circulation prevailing in the kiln at the beginning of the burn. The importance, therefore, of having ample stack draft through the use of higher chimneys or such which are kept heated at the beginning of water smoking is evident. Our down draft kilns, for instance, invariably suffer from very poor initial draft, a condition which is paid for by the loss of valuable time. Not only is the water smoking process proper retarded by the deficiency in draft but it may be greatly lengthened through the absorption of steam by the ware in the cooler portion of the kiln. Such a condition greatly aggravates matters since, so to speak, a new start must be made in order to expel the accumulated excess water taken up by part of the kiln charge. It would be a good investment, therefore, to provide, if necessary, mechanical draft through the use of portable exhausters. The rate of raising the temperature during the water smoking should be such that there is no marked difference between the kiln temperature and that of the interior of the product. An excessive rate of heating invariably causes strains which may lead to damaging of the ware. The permissible rate of heating varies somewhat with the clay structure, that is, with the amount of hygroscopic water carried by the clay and with the artificial structure imparted to the material in pressing.

It is evident that clay particles possessing but limited cohesion, as in dry pressed ware, can not withstand the strain brought about by a decided temperature difference between the exterior and the interior temperature of the ware. Very slow drying becomes imperative in such a case. However, in the case of plastic clays previously dried sufficiently, it would seem that the water smoking should be completed in 15 hours when heated to 300°C, or at the rate of 20°C per hour. Provided that adequate circulation is maintained there is no reason why this should not be done, even in the case of heavy clay products. The industrial importance of this statement is apparent and is worthy of careful consideration.

The temperature range of water smoking lies between 100 and approximately 240°C for properly dried material. Overlapping of the heat absorption ranges involving the pore and hygroscopic water occurs upon insufficient drying.

Allowing 24 hours for the completion of water smoking, satisfactory results may be obtained by increasing the temperature at the rate of about 12°C per hour, or by following such a heating curve as is suggested in the diagram of figure 17. The use of base metal thermocouples is, therefore, strongly recommended for the proper control of this important process.

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