A STUDY OF THE OPERATION OF A DRESSLER TUNNEL KILN¹

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ABSTRACT

Before installing a Dressler tunnel kiln, Norton Company made a study of an existing kiln. At Steubenville, Ohio, the kiln was found to be working well; repairs were small, economy in fuel, labor and firing time had resulted. The heat distribution was found to be variable but subject to control. The amount of rejected ware was very small and in no case could it be charged definitely to the kiln.

This kiln was investigated by the writer for a period of five weeks for the purpose of determining its desirability as an addition to the kiln equipment of Norton Company. Permission has been obtained from both the American Dressler Tunnel Kiln, Inc. and Mr. Geo. W. Cochran, Secretary and Treasurer of the Ohio Valley Clay Company to publish the results of the observations for the benefit of those who are interested in tunnel kilns.

The success of the investigation was made possible by Mr. Cochran's kindness to the writer; he was quite willing to facilitate the tests and it was a pleasure to discuss the results with him. Thanks are due him at the outset for allowing this work to be done.

General Description

There is a considerable amount of literature available relating to the principle upon which the Dressler tunnel kiln is based, notably in volumes 17 and 18, Transactions of the American Ceramic Society. A brief description of the kiln, however, may not come amiss here.

The kiln is of the muffle type. The fires are in refractory muffles on either side of a track extending the length of the

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kiln. The firing zone is about midway of the length. The ware, which is placed upon cars, is sent gradually through the kiln by means of a pushing device located at the head end; it is gradually heated by the products of combustion drawn through ducts along the kiln walls between which it passes, fully fired while passing the firing zone, cooled gradually as it approaches the exit and finally when taken from the kiln is ready to be removed from the cars.

Figure 1 is a schematic drawing of the cross section of the kiln. Combustion takes place in the double walled, trapezoidal shaped chambers on either side; these chambers are located throughout the forward end of the kiln and extend somewhat beyond the

FIG. 1.—Schematic drawing of Dressler kiln through firing zone.

middle. Combustion takes place in the chambers at about the center of the kiln; the products of combustion are brought toward the forward end by means of an exhaust fan connected to the long lines of chambers on either side. Thus the chambers can be thought of as long horizontal double-walled chimneys between which the ware passes on its journey through the kiln.

The transfer of heat from the chambers to the ware probably takes place in two ways: (1) by radiation; (2) by convection currents through the channels between the inner and outer walls of the chambers. The chambers are constructed so as to allow the atmosphere of the kiln to circulate around them and yet the gases of combustion can not escape into the kiln.

After passing the soaking zone of the kiln the ware passes between pipes on either side of the kiln chamber which extend from the exit end of the kiln nearly up to the burners. Air from the kiln shed is taken into these pipes near the exit end of the kiln, brought nearly up to the burners and there exhausted outside the kiln. As the air passes through the pipes

FIG. 2.—General appearance of outside of kiln; picture taken from near exit end. Note the intake ends of the cooling pipes for one side.

it becomes heated by abstracting heat from the ware close to it. The ware, as it leaves the soaking zone, passes between these pipes relatively hot at first but much cooler toward the exit. The cooling air is always in the pipes and so does not come in contact with the ware, hence the cooling also is done by radiation and convection.

The iron framework and wheels of the cars are kept cool by the circulation of water in pipes close to these parts.

The pusher is built on the principle of a horizontal screw jack, and is motor driven. After reaching the end of its stroke either forward or back it stops automatically.

Dimensions

This kiln is about 300 feet long by about 14 feet wide at the widest part, outside dimensions. The tie rods binding the buckstays together are about 11 feet above the floor. The cross section of the kiln is such that ware can be set 48" above the car floor and 44" wide. The car floor is about 30" above the track.

At the entering end of the kiln a space of about 12 feet by 6 is required for the pushing machine which moves the cars through the kiln.

Movement of Cars

Outside of the kiln, and running parallel to it, is a trace where the cars are unloaded and set. After being set they are run onto a transfer truck at the entrance of the kiln. This transfer is run into the kiln with the car on it and locked so that the car can be pushed onto the track within the kiln. Outside the kiln and in line with the track running through the kiln is the pusher, which pushes the entering car into the kiln and at the same time pushes the line of cars within the kiln ahead of it.

During the period of operation one car was put into the kiln every four hours, or six cars a day. Since the kiln held 47 cars, it required just under eight days for the cars to go completely through. The average rate of travel was $1\frac{1}{2}$ feet per hour. At the same time that a car was being pushed into the kiln another car was being pushed onto a transfer at the exit end. Before another car can be put into the kiln, this car on the exit transfer must be taken out and put on the outside track.

At either end of the kiln the openings for the cars were closed by rolling metal doors; these were kept closed except when cars were either locked in or taken out. The cars were set entirely outside the kiln previous to locking in; the ware was removed from the cars not far from the exit end of the kiln at a place convenient to the warerooms.

Cars

The cars were built up on a cast iron frame each supported by four roller bearing wheels. The superstructure was made of hollow fire-clay blocks filled with Sil-O-Cel powder. The floors of the cars were made of heavy clay slabs which were directly supported by fire-clay girders. These are well shown in figures 3 and 4. The dimensions of the car floor, and thus the setting area, are 44" by 72". The floor is supplied with a number of holes which allow convection currents to pass through the ware and thence through the channels around the muffles.

The iron frame of the car was two inches longer than the clay superstructure. As the cars were pushed through the kiln, each pushed all the cars ahead of it by means of the iron frames. Each car was provided with a tongue on one end and groove at the other in the fire-clay piece near the bottom thus presenting a baffle for the heat, tending to keep the iron frame cooler by preventing direct radiation. The cars weigh about two tons and their setting capacity is in the neighborhood of three tons. They were numbered and always kept in numerical order, thus making it easy to locate a car in the kiln.

Outside the kiln the cars could be readily pushed by hand. When taken from the exit transfer they were pushed a short

FIG. 3.—General appearance of an empty car.

way along the outside track to the drawing locality; after drawing, the car was pushed toward the setting location which was near the forward end of the kiln. After setting the setting gang pushed the car toward the head end to await its turn into the kiln. The location of the setting position was at such a distance from the head end of the kiln that enough space was allowed for the number of set cars to last over Sunday. Similarly, at the other end, the unloading space was far enough away from the exit so as to allow space for all the cars which came out during Saturday and Sunday.

Pyrometer Equipment

A good pyrometer equipment is quite essential on any tunnel kiln. The correct temperature curve having been determined

for the ware, it is only necessary to hold the temperature constant throughout the soaking zone in order to insure proper firing. Cones cannot be used to control the burning in the way they are in a periodic kiln; they should be used frequently however, to check the firing conditions. In a periodic kiln the temperature is raised or held steady until the desired cone deformation is reached. In the tunnel it is impossible to hurry or slow up one car without doing the same to the entire train. Therefore after the kiln temperatures have been regulated so that the desired cone deformations are reached, then these temperatures should be held constant. A good pyrometer is invaluable for this purpose.

Other instruments can probably be used to good advantage on a Dressler kiln; draft gauges and combustion meters would undoubtedly prove of value. At Steubenville the kiln was provided with a pyrometer equipment and a draft gauge for obtaining the draft at different points in the combustion chambers.

Heat Distribution

At intervals throughout the length of the kiln thermocouples projecting down into the crown about 2" were supplied for measuring the temperatures at these points; couples were also inserted into the combustion chambers, at nearly the hottest place. The temperatures at two couples in very nearly the hottest place in the crown and at one couple in the combustion chamber on either side were recorded; at all other points, seventeen in all, the temperature was indicated.

Figure 5 gives the heat curve of the kiln throughout its length. The general shape of the curve (except at station 11) is correct although the actual temperatures recorded in the soaking zone of the kiln may be in error. The temperatures were measured in most cases with a platinum-rhodium thermocouple and a Leeds and Northrup potentiometer. At a few of the stations however the kiln couples could not be readily moved in their protection tubes so the best attainable temperature as given by the couple at that point was used. All readings were corrected for cold junction temperature. Stations 16 and 17 were located in the combustion chambers, one in either side. It will be noted

that these temperatures ran about 100° higher than the highest kiln temperature indicating good heat conducting properties of the silicon carbide chambers. Not much reliance could be placed in the reading at No. 11 station; the couple was apparently not giving truthful readings yet it could not be removed without further injury, a step which the writer could not readily undertake.

FIG. 4.—A car just out of the kiln.

The curve in figure 5 is a distance—temperature curve and should not be confused with a time-temperature curve usually given for kilns; it would become a time-temperature curve if one hour were substituted for each one and one-half feet. If the rate of travel were hastened, *i. e.*, made faster than $1\frac{1}{2}$ feet per hour, the effect would be to compress this distance-temperature curve horizontally in order to obtain the time-temperature curve. This curve and the time-temperature curve coincide when the rate of travel becomes one foot per hour. During the time of observation the rate of travel was $1\frac{1}{2}$ feet per hour; at intervals since then it is understood that this kiln has been run successfully as fast as two feet per hour.

TABLE OF TEMPERATURES AT THE STATIONS INDICATED ON FIGURE 2

Station	Cold junction temperatures, °C	Corrected temperatures, °C
1	25	214
2	33	385
3	30	535
4	38	765
5	40	1030
6	40	1108
7	58	1145
8	110	1199
9	136	1197
10	75	1165
11	46	585?
12	35	601
13	30	458
14	28	389
15	27	211
16	80	1299
17	70	1292

The temperature at either end of the kiln was fairly high; at the entering end it was close to 150°C , and the ware came out at 160°C . The temperature at the top of the kiln was much higher than at the floor of the car at the two ends. Although these temperatures may seem high they were not too

FIG. 5.—Distance-temperature curve of Dressler kiln.

high for the ware put through this kiln. A kiln constructed for ware which would not stand these entering and leaving temperatures could readily be designed.

The longitudinal temperature curve is a mechanical achievement; given the required curve through which a certain ware must pass for its proper maturity and cooling, a Dressler kiln can be constructed which will fulfill the required time-temperature requirements. The real test of a kiln of this type comes when at the same time a demand is made that the heat distribution through the cross section shall be within certain limits. Considerable time was spent in studying the cross sectional heat distribution. This was done by means of distributing pyrometric cones and Veritas discs at many points over the setting space.

The cross sectional heat distribution was found at times to be very good—less than one-third of a cone—and at other times faulty—as much as two cones difference. This may look discouraging but in reality is quite the opposite, for if the distribution had always been poor no matter how it was aided by changing setting methods then there would have been reason for lack of enthusiasm for the kiln. Since the distribution was at times very good, the problem was to find out why it was good and to try to so operate the kiln that it would always be good. The real solution turned out to be openness of setting; cars set fairly open gave good heat distribution; when set close or tight the distribution was not so good. This does not necessarily mean that cars can not be set tight with good heat distribution but it probably does mean that a good distribution can not be obtained where tightly set cars are locked into the kiln with openly set ones; a uniform setting should be adopted for best results.

The data for the heat distribution results follow: Cone pats were made up of cones 9–10–11–12. Veritas discs were usually placed with the cones.

Figure 6 shows the result of one test made over the cross section of a car; the top cone pats show cone 11 fairly well down whereas at the bottom cone 11 is only about half over. At both

the top and bottom it appears that the center was not so hot as the outsides. The figures on the discs represent the shrinkage in percentages; these vary from 8.05% to 8.45%.

FIG. 6.—Left—Diagram showing the positions where the cones were set. Right—Cones 9, 10, 11, 12 after passing through the kiln.

Figure 7 shows the result of a second test where again the differences in cone deformation amounted to less than half a cone. There is a tendency here indicating that the car was hotter on the outside than at the center at both top and bottom.

FIG. 7.—Left—Diagram showing the positions where cones were set. Right—Cones 9, 10, 11, 12 after passing through the kiln.

From the above it will be seen that the greatest difference in temperature throughout a car is as likely to be from center to outside as from top to bottom. Figure 8 illustrates a test made to see if a more open setting might improve the heat distribution from center to outside. A row of cones and discs were set across a car between flux blocks set rather openly; the floor plan is attached and shows a space of eleven inches wide extending across the car. An inspection of the cones shows only infinitesimal differences. These results are checked by the discs which show practically no differences in percentage shrinkage.

Several other tests were made which showed that the cones must be placed in relative positions in order to compare them; for example, cones exposed toward both sides and top showed a greater deformation than cones which were protected by ware from the top. This is an indication that there were convection currents moving through the muffle walls and the ware, as claimed by the American Dressler Tunnel Kiln, Inc.

FIG. 8.—Above—Floor plan of car showing where cones were set between the ware. Below—Cones 9, 10, 11, 12 after passing through the kiln.

Defective Ware

The ware manufactured by the Ohio Valley Clay Company is glass house refractories. A large portion of the ware put through the kiln during the time of observation was rectangular shaped blocks weighing from three to seven hundred pounds; occasionally there would be set a piece weighing over a ton and often times on the same car with pieces weighing only a few pounds.

The amount of defective ware coming from the kiln was surprisingly small, and it is possible that the cause of rejection originated in the dryroom. A few pieces which were thought to

have minute cracks were marked before locking into the kiln; these always came out cracked. For this particular ware the kiln is admirably suited. No damaged ware came through during the five weeks observation, which could be definitely charged to the kiln.

Kiln Repairs

The kiln had been running about eight months at the time of observation; it was remarkably free from cracks, in fact, there were no obvious ones, but in looking for them there were found two fine hair-like cracks which were of no consequence.

During this time the cars had been without repairs. While the writer was at Steubenville three cars were repaired; a portion of the top slab was replaced on each. These were said to be the first repairs to the cars.

There is a considerable amount of mechanical equipment connected with the kiln, two fans, a water pump and the pusher, all motor driven. None of these had given the slightest trouble, yet they had seen twenty-four hour per day service since the kiln was started. Although this is a remarkable achievement for the mechanical equipment it would seem that considerable chance is being taken in operating a kiln of this sort without duplicate parts. The stoppage of the main draft fan means that the fuel supply must be immediately turned off to avoid filling the kiln shed with smoke. The cooling air fan or the water pump could not properly be down for more than an hour.

During the eight months period which the kiln had run up to the time of observation there had been one shut down of a purely accidental nature. A workman dropped a plank on the rheostat governing the motor operating the water pump; this stopped the pump and, since it ran very silently, nobody noticed that it was stopped for some time. Upon discovery of the stoppage the pump was started; in the meantime the water pipes had become quite hot and when the cold water was pumped in, the quick contraction of the pipes broke some of them allowing water to escape into the kiln chamber. In order to repair the trouble the kiln had to be partially cooled. A loss of about ten days resulted.

Fuel

The fuel used at this kiln was natural gas, which is an ideal fuel for the Dressler kiln. The amount used averaged about 73,000 cubic feet every twenty-four hours; occasionally the consumption reached 82,000 and on one day it was as low as 65,000 cubic feet. The gas pressure was held constant by regulators on the main line and also on each line running to either side of the kiln.

The reason for the wide fluctuation in gas consumption is not quite clear. Two possible reasons present themselves, changes in the B. T. U. value of the gas and improper combustion. No means of determining the B. T. U. value were available. Neither was there a means of directly determining the composition of the exhaust gases at hand, but certain fluctuations in the kiln temperatures indicated that the best combustion possible may not always have been obtained.

The temperature of the exhaust gases was about 240°C, showing that most of the heat of combustion had been given up to the ware before being exhausted out of doors.

This kiln was built with the proper facilities for burning producer gas. A gas producer was installed in close proximity to the kiln but had never been used up to the time of observation. It has recently been learned that this kiln has been run with producer gas with excellent results. The kiln is readily adaptable to either natural, city or producer gas and fuel oil.

Kiln Capacity

It is somewhat difficult to make a just comparison of kiln capacities where the wares burned are of varying types. The Dressler kiln is admirably adapted to the burning of glass house refractories where the ware possesses sufficient strength to require no sagging and its shape is well adapted to economical setting on the car tops.

At the Ohio Valley Clay Company the Dressler kiln was doing the work of nineteen periodic kilns of various sizes. Their operating time had been cut from twenty-one days to about eight days and their output had increased fifty per cent. Their gas consumption had been cut by an enormous amount and a

saving in labor of about 50% was claimed. All these claims looked entirely possible after watching the manner in which their ware was handled and comparing these methods with a mental picture of their former methods.

To express the capacity of a Dressler kiln in terms of periodic kilns, one must make an intelligent guess unless considerably more is known about the best time-temperature curve of a particular ware than can be gained by the operation of a periodic kiln. For example, we attempt to operate a periodic kiln so that all ware comes out good, the temperature rise is slow enough so as not to overheat the outside ware in the water smoking period and as a result the center ware is raised over-cautiously for we can not do otherwise; likewise in cooling we must cool for the outside ware and let the center ware take a much lower rate. In other words we are dealing with a large unit which is always at non-uniform temperatures and which must be fired over-cautiously so as to be on the safe side.

If the exact time-temperature curve by which a ware must be fired is known then, given the relative setting areas of the two kilns, it is entirely possible to express the capacity of a Dressler in terms of periodic kilns. In general, however, the temperature and safe minimum time to which a ware can be successfully fired is not known and because of this the Dressler kiln is able to cut down the time of firing in periodic kilns. Since the kiln gives practically uniform cone deformation throughout the cross section it is evident that the car rate can be started safe and then speeded up to the limit which the ware will stand. Just what ultimate rate the ware will stand must be more or less of an intelligent guess unless this rate has been determined in some other manner than in a commercial kiln, as for example in a laboratory furnace.

There is another reason which makes the time-temperature guess for ware fired in a periodic kiln still more problematical, this is the condition of the kiln atmosphere. Whether the atmosphere is oxidizing or reducing is not always known for a periodic kiln, nor is the part played by the atmosphere always known. In the Dressler kiln the atmosphere can be controlled and its effect upon the ware studied.

Taking these points into consideration the best guess we could make as to the capacity of the Dressler kiln was somewhere between five and ten periodic kilns. The periodic kilns compared are what are known as fifteen foot, down-draft, circular kilns; the setting space is about thirteen and one-half feet in diameter between bag walls and about ten feet high.

Economy

It must be readily admitted that a periodic kiln is extremely wasteful of fuel. A Dressler kiln, and probably tunnel kilns of other makes, will undoubtedly save fuel. An estimate of fifty-per cent savings is conservative.

The savings in labor by the use of a Dressler tunnel kiln, or other car tunnel kilns is somewhat problematical. At Steubenville on natural gas the care of the kiln was under one man who also had charge of the setting and drawing. At night the watchman put in a car every four hours, but was frequently at places remote from the kiln during the interim. As far as manual labor is concerned one man on a shift can take care of the kiln lock in the cars and take them out. If producer gas is used an additional man on the producer would probably be necessary.

The saving in setting and drawing labor resulting from a tunnel kiln must depend somewhat on the type of ware and the methods in use with periodic kilns. Where large heavy pieces are fired mechanical means can be used to good advantage on the Dressler cars for both setting and drawing. The saving resulting where the ware is small and uniform in size and comes to the kiln in saggars will be less than where it is large, irregular in shape and must be packed in quartz at the kiln. The fact that all ware is set in the open at one place and drawn in the open at another should result in a saving of labor over that required for a periodic kiln because the working conditions are much more pleasant.

Additional Dressler Kilns

During the time of investigation at Steubenville advantage was taken of the opportunity to visit other plants in that vicinity where five additional Dressler kilns were seen. Although no

study was made of these kilns, conversations with the operators of them proved that they were giving entire satisfaction both in reduction in cost and in quality of ware. All of these kilns were burning natural gas although they were equipped for burning producer gas and in some cases had operated on it.

Possible Difficulties

The stopping of a Dressler kiln is of a somewhat serious nature; it causes contraction and its attendant cracking which is objectionable. The low cost of maintenance of this kiln is probably dependent upon its continuous operation. A few of the possible difficulties which may be encountered are listed here.

The combustion chambers may burn out. These should be made of the proper material to withstand the temperatures used and the action of the fuel.

Suitable fire-brick should be chosen for the crown; the weight on the crown is small but the continuous heat allows the crown to become hot throughout its thickness.

Care must be exercised in setting so that no ware will fall off a car inside the kiln. Some ware lends itself very well to stable setting; this is particularly true at the Steubenville kiln. But there are other wares which can not be set so stably, as flux blocks, and here great care must be used.

The stoppage of fans or the pump is serious but this may be eliminated by a duplicate equipment.

Advantages

The Dressler tunnel kiln can usually give a saving in firing time; this is because its cross-sectional heat distribution is practically uniform.

A saving in fuel can undoubtedly be accomplished.

Waste heat from the kiln can readily be used for heating or drying purposes.

The expense account for repairs should be small. At all plants visited where repairs had been made an accident had been the direct cause.

A muffle kiln gives better combustion control than an open-fired kiln. Where ware is usually sagged the need is elimi-

nated by the muffles in the Dressler kiln. The need for saggars for protecting the ware from discoloration is eliminated in the Dressler kiln where the fires are enclosed in muffles. The muffles may seem like needless expense where muffling of the ware is not necessary, but it is believed that better combustion control and more uniform and constant temperatures can be maintained by their use than without.

The atmospheric conditions within a kiln are often times important; some wares require an oxidizing and others a reducing atmosphere. In the Dressler kiln the atmosphere is always oxidizing unless it is made reducing by the admittance of a particular gas.

There should be a saving in breakage of kiln furniture in the tunnel over that resulting from a periodic kiln. The setting height is from one-half to one-third that of the periodic kiln, therefore there is a correspondingly lesser weight on the furniture. The uniform heating and cooling with the elimination of occasional flashing ought to prolong kiln furniture life.

Summary

The Dressler kiln was found to be giving very good satisfaction at the Ohio Valley Clay Company as well as at a number of other plants.

The cross-sectional heat distribution seems to be subject to control and differences greater than half a cone can probably be eliminated.

The control of the kiln seemed very simple, at least with natural gas.

Savings in fuel can undoubtedly be made by the use of this kiln. Savings in labor, rejected ware, kiln furniture, and kiln repairs can probably be made over those required for a periodic kiln.

A saving in firing time over that required in a periodic kiln ought to be accomplished; its amount can only be estimated. At Steubenville, the firing time had been cut to one-third the periodic kiln time.

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