THE TUNNEL KILN APPLIED TO CERAMICS¹

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There are three principal items to consider in firing tunnel kilns: (1) Heat generation, (2) heat distribution, (3) heat absorption.

Heat generation requires a proper combustible, proper oxidizing agent, proper temperature and in the proper proportion, and a proper mixture of the above. There are two factors in the generation of heat, which are very often misunderstood, *viz.*, the quantity of heat and the intensity of heat.

It is a well known fact that some operations require a higher temperature than others, but this must not be confused with the fact that some operations require a greater amount of heat at certain temperatures. (Example—water.)

The intensity of the heat determines the time element of an operation. It is a matter of laboratory record that heat conductivity, radiation, absorption and convection are proportional to the difference of temperature of the heated substances and the heating medium, the constant varying with the different substances.

Heat distribution and heat absorption are very closely related and cannot be considered independently. In firing porcelain, there are four (4) distinct danger zones:

1. The ware is heated up until it reaches the boiling point of water.
2. When the contained water of crystallization begins to break up—this zone to consider safely is between 750° and 900° F.
3. Where the less refractory ingredients begin to fuse and the whole mass becomes more or less soft. The firing between these stages can be quite intensive
4. After the firing (soaking zone) cooling begins, and with some material rapid cooling is permissible to the temperature of a dark red. After that a gradual and slow cooling is necessary.

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The above brief summary of the danger zones shows that the very exacting requirement in firing porcelain is obviously difficult to observe, when applying to the beehive kiln. The heating of the whole mass of ware and saggars cannot be easily accelerated or retarded rapidly.

This brings us to an arrangement where a proper cycle may be obtained by localizing the intensity of heat in certain portions of the kiln and have the section so proportioned that the material being moved at constant speed is for a longer time under the influence of the heat at the point in question.

The main factors controlling heat distribution and heat absorption in a tunnel kiln are: (a) Size of the car, (b) amount of ware on the car, (c) size of passages. Items *a* and *b* are usually predetermined by the output contemplated. It is really the proportion of the passages and the combustion chamber that determines the performance of the kiln and its efficiency. Assuming that the kiln is proportionally designed to take care of the output, the question of proper firing becomes of the most importance.

There is no set rule for firing of all fuel, except the fundamental fact that sufficient space must be provided for combustible gases and proper provision made for the mixture of those gases with the oxidizing agent. Independent of the original fuel, it is the gases that produce combustion. In coal firing the gases are obtained by a partial distillation. In oil firing, the gases are either vapors or true gases of the oil, and the closer the state of the oil approaches the state of perfect gas the more efficient is the combustion. That is why oil-firing system that gassify the oil before combustion obtain higher efficiencies and higher temperatures. Gaseous combustibles are not only conveniently mixed in the proper proportion with air, but ignite immediately on coming in contact with the proper temperature without going through any intermediate stages.

The size of the combustion chamber is determined by the kind of fuel used. When solid fuel is used, large volumes of gases are distilled off and a large excess of air is usually employed. All this calls for a large combustion chamber. When liquid fuel is used, the combustion chamber may be somewhat less than with

solid fuel, but just big enough to give sufficient travel for the atomized or vaporized oil to gasify. When gaseous fuel or liquid fuel in gaseous state is used, the smallest combustion chamber can be employed.

It is interesting to note that with the truly gassified oil the size of the combustion chamber may be much smaller than if gaseous fuel is used. This is explained by the higher heat contents per cubic foot of gassified oil as compared with the natural, city, or producer gas.

When a concentrated gaseous fuel is used and the air is so controllable that an amount as close to the theoretical requirement as possible is used, the calculation of the combustion chamber to correspond with the proper distribution of heat is possible with a fair degree of accuracy. In firing ceramics, where the final result is obtained by a close following of the proper time temperature cycle, especially through the danger zones enumerated above, proper distribution of heat is vital. As distribution and generation of heat are closely interlocked, proper combustion is really the basic requirement for successful operation. The continuous kiln not only gives a proper distribution but allows flexibility of design of the combustion chamber.

The muffle type of kiln seems to be as yet the most efficient furnace for firing of porcelain as the passages for the production of combustion can be lengthened, widened, deflected or arranged in any way to correspond with the quantity and intensity of the heat required at any particular point. The proper length of the kiln is generally a matter of considerable discussion. In our opinion it is a matter of simple calculation and depends solely on the output contemplated and the time temperature cycle employed.

For the single tunnel kiln, if you multiply the length of the car in feet by the number of cars to pass through the kiln per day by the time in hours of complete cycle of firing, and divide by 24, you will get the length of the kiln. If this item is not divisible by the number of cars add to this enough to make an even amount of cars. If this is a double compensating kiln, half of this length is sufficient.

As compared with a periodical beehive kiln, the continuous kiln has the following advantages:

1. The losses due to the defective placing, defective distribution of heat and inadequate control of the heat, are eliminated.
2. The ware is handled with maximum convenience as the placing is done outside of the kiln and only shoulder high.
3. The saggars are done away with. This not only means a saving of fuel, but a considerable saving in cost of saggars.
4. The losses due to intermittent heating and cooling of the kiln are eliminated.
5. Smaller up-keep expense.
6. The heat stored in the ware is utilized for preheating the incoming ware and the air for combustion.
7. The firing cycle is considerably shorter.

The double compensating kiln has many advantages over the single tunnel kiln, *viz.*:

1. It requires a shorter floor space for the same output. This gives a structure which is better proportioned for placing in an ordinary building.
2. Radiation losses are much less and therefore it is more economical. The middle wall of a double kiln takes the place of two outer walls thus saving one-half of the side surface radiation.
3. A better control of temperature and quantity of heat is obtained. As the heat is delivered to the ware by convection of gases and not by radiation from the walls, it is obvious that the distance that this gas will have to travel is the limiting feature in the control since these gases can be sent only a short distance without excessive loss.
4. Less initial expense for building and equipment. A double kiln requires half as much side plating and buckstays, wall insulation and usually less brick as the center wall is thinner than two side walls. The foundation is shorter and wider; this resulting in a better and stronger structure. Less attention has to be paid to expansion joints and piping is considerably shortened.

5. Less maintenance expense. The shorter the kiln, the fewer are the number of expansion cracks, which are inevitable in spite of all provisions for expansion joints.

With a properly designed kiln (that is, with a commercially scientific control of heat generation and distribution), firing ceases to be the problem of an expert. The cycle of firing once determined can be strictly adhered to, and anyone with enough intelligence to turn the valve in the right direction can be entrusted with the operation. It is not too optimistic to state that in the future, and let us hope in the near future, ceramics as an industry will be put on the same basis as any other manufacturing enterprise and the black magic of firing eliminated.

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NOTICE—*Discussion of this paper will be published later as part of the Discussion of Tunnel Kilns.*