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Evaluation Of Thermal Efficiency Of Bull's Trench Kiln

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INTRODUCTION

The consumption of slack coal for brick burning in India is increasing at a fast rate. It amounted to 1.75 tons in 1958[1] and the current consumption may be conservatively estimated at 2 million tons. Consumption is certain to increase many times in the future to burn the bricks required for various development projects. There is already a desperate shortage of slack coal as also of wagons for transporting it. So far as the brick industry is concerned the consumer generally has no choice in the selection of coal and has to make the best use of whatever quality is supplied to him. Economy in fuel has therefore become a necessity and the kiln burner has to take every care to keep fuel consumption down to a minimum.

The need is therefore being increasingly felt for a probe into the firing practices followed in the brick kilns in India and also for a systematic study of the thermal behaviour of the Bull's trench kiln which happens to be the only form of continuous kiln used by the brick industry in this country. The practical difficulties of operating a Bull kiln and its relatively poor performance are fairly well-known but little attempt has so far been made to improve its design. Hence the possibility of developing a trench kiln of an improved design is being examined at the Central Building Research Institute. In this paper the basic considerations involved in the evaluation of the thermal efficiency of continuous kilns of the type of the Bull's trench are discussed.

FUNCTIONS OF A KILN

The thermal efficiency of a furnace or a kiln is evaluated in the light of the functions it is expected to perform. For instance, a kiln may be designed with high thermal efficiency but unless it is able at the same time to deliver a high percentage of saleable goods and maintain a desired rate of output, it will be of little value to the industry.

The functions of a brick kiln may be broadly stated to be:—

(i) to secure the liberation of combustion energy of the fuel at a desired rate;

(ii) to secure transfer of heat liberated by combustion to the charge without excessive temperature difference between the gases and the brick surface; and.

(iii) to maintain a desired rate of output of finished products with an economic rate of ruel consumption.

Evidently the most important function of a kiln is its ability to fire goods at a desired rate with a minimum of fuel consumption. Economy of fuel in a continuous brick kiln is secured in two ways, viz.

(i) by the maximum utilization of the heat energy obtained by the combustion of fuel by good heat transfer and counter-flow heat exchange between the combustion gases and the bricks; and,

(ii) by the maximum recuperation of the sensible heat content of the cooling brick and utilizing it in preheating the combustion air and also in drying freshly set bricks.

THERMAL EFFICIENCY

While examining a kiln of a particular design it is of importance from the point of view of fuel economy to determine how and to what extent the kiln is performing the above functions — which in other words means, to determine its 'efficiency'. Efficiency of a kiln may be defined as the percentage relation between the heat energy that is transferred usefully to the goods and the energy that is actually supplied. The determination of thermal efficiency, therefore, involves the evaluation of the theoretical heat requirements and requires a complete analysis of the manner in which the combustion energy of the fuel has been utilized in completing the various processes and what part of it has been dissipated. Such an analysis provides the necessary data for drawing up a 'thermal balance' in which the heat input to the kiln is balanced against the heat output. The credit side of the thermal balance shows the heat input comprising of:

i) the heat derived from coal; and,

ii) the energy obtained from the combustion of carbonaceous matter in the clay and also from any other exothermic reaction taking place.

To obtain the total heat input, therefore, the calorific value of the coal used should be known. The amount of carbonaceous matter present in the clay should also be found, the thermal yield per pound of carbonaceous matter burnt being assumed to be equivalent to a pound of dry-ash-free fuel, i.e. about 15,000 b.t.u.

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The debit side of the thermal balance shows the heat output comprising of:

i) heat required to evaporate the mechanically held water;

ii) heat required to evaporate the combined water;

iii) heat required to evaporate the moisture in coal;

iv) heat required to evaporate the moisture produced by the combustion of hydrogen in coal;

v) heat required to decompose calcium carbonate in the clay;

vi) heat required for completing other irreversible reactions in clay;

vii) sensible heat in the dry products of combustion passing into the chimney;

viii) heat contained in the CO_2 from the decomposition of calcium carbonate;

ix) heat contained in the excess air leaving the kiln;

x) potential heat in the combustible matter in the ash and in the unburnt gases escaping from the kiln;

xi) other heat losses including losses due to radiation, conduction and convection from the kiln structure (by difference).

In calculating the heat values involved in the processes mentioned above, it is necessary to test the brick as set for its moisture content. The amount of calcium carbonate present in the clay, the percentage of combined water and the total loss-on-ignition of the clay should be determined quantitatively. The composition of the waste gases leaving the kiln and the percentage of the excess air passing through the kiln must also be determined at regular intervals.

In the determination of thermal efficiency of kilns, the evaluation of the heat required to raise a clay to a given temperature has so far remained a difficult problem. Unless this value is known the theoretical heat required for firing the goods cannot be determined. Skimmer[2] suggested that the heat H (btu) required for firing the goods is given by:

$$H = 0.01\,(100 - q)\;(t_m - t_e)Mh$$

Where,

q = mechanical water in green ware;

t_m = temperature of ware (max. °F)

t_e = temperature of entering ware (°F)

M = weight of green ware (lbs.)

h = specific heat (moisture free) of green ware from entering to max. temperature.

It will be observed that to obtain the value of H by this formula the value of the specific heat of the green ware (h) over the entire temperature range must be accurately known.

In the case of stable materials such as silica bricks, the heat supplied to the goods may be determined by multiplying together the weight of the goods, the mean specific heat over the firing range and the difference between the temperature of the goods as set and the final temperature. However, in the case of clayware calculations are complicated by the fact that the specific heat of clay does not remain constant but continues to change over the entire firing range. The changes in specific heat occur as a result of various irreversible chemical and physical changes involving endothermic and exothermic reactions which take place during the heating of clay. The reactions which commonly occur are:— (i) combustion of carbonaceous matter; (ii) decomposition of carbonates, sulphates, hydrates, etc., (iii) decomposition of the clay molecule; (iv) formation of Al_2O_3 (v) latent heat of fusion, and (vi) the thermal changes accompanying the solution or crystallization of various silicates, aluminates, etc.

In determining, therefore, the quantity of heat theoretically required to be supplied to the goods in firing upto a given temperature the interval specific heats over the entire temperature range must be accurately known. Attempts have been made by several workers, [3, 4, 5] to determine the interval specific heat of kaolins, ball clays and fire clays over various ranges of temperature. However, due to experimental difficulties and the absence so far of a standard procedure and technique of determining the interval specific heats, the work has been limited more or less to the purer varieties of clays only. The values vary from clay to clay and no reliable values of interval specific heats have so far been obtained for the common brick clays. When the interval specific heat of the unfired clay is known, the heat required to fire a unit mass of air-dried clay from the temperature of setting to the average maximum temperature can be obtained. The total heat supplied to the goods can then be determined by multiplying the value for a unit mass of clay by the total weight of air dried goods in the kiln and adding to the product the quantity of heat required to evaporate the mechanically held water.

An alternative method suggested by Rowden and Green[6] takes into account the specific heat of the fired ware. The sensible heat content of the fired bricks at average maximum temperature is determined by multiplying together the weight of the fired goods, the mean specific heat of the fired ware and the rise in temperature. To this figure the heat required to complete other thermal reactions are added to obtain the total heat supplied to the goods. This method of calculation has also been recommended in the B. S. Test Code No. 1081 : 1942.

The British Standard Test Code for Kilns Firing Heavy Clayware defines thermal efficiency as the percentage relation between the heat supplied to the goods and the total heat input, i.e.,

$$E = \frac{\text{Heat supplied to the goods}}{\text{Heat supplied to the kiln}} \times 100$$

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According to this test code the heat supplied to the goods is determined by finding the sum of:

i) the sensible heat in the fired bricks at the average finishing temperature;

ii) the heat in the water vapour from mechanical water at 150°C;

iii) the heat in the water vapour in combined water at 600°C;

and the heat required to complete the following processes:

iv) heat required to decompose carbonates in clay;

v) heat required for completing other irreversible reactions in clay.

Although this test code has been recommended for the three usual classes of brick kilns viz., (a) intermittent (b) continuous car-tunnel, and, (c) ring tunnel and chamber continuous kilns, the code is strictly applicable to one class of kilns only, viz., the intermittent, as discussed below.

It will be observed that in continuous kilns utilizing the principle of counterflow heat exchange, the whole of the sensible heat in the bricks (item 'i' above) is theoretically recoverable and in practice is largely recovered by the incoming combustion air and excess air which are thus preheated. Similarly the heat contained in the moisture, excess air and the products of combustion is almost wholly transferred to the bricks in the pre-heating and drying zones, so that finally the gases leave the kiln at a temperature of 100°C to 150°C which is very much below the maximum firing temperature (approx. 1000°C.). As a result of these heat economies the fuel consumption, i.e., the heat input of the kiln is considerably reduced. If, therefore, the efficiency of a continuous kiln is evaluated on the basis of the B.S. Test Code, the values obtained would be very high, sometimes exceeding 100% and would not therefore present a true picture.

In continuous operation the heat contained in the kiln and flue structures remain substantially constant and hence is not included in the thermal balance. Theoretically therefore, the thermal efficiency of a continuous kiln may be determined by finding the percentage relation of the total heat input and the theoretical minimum heat requirements for completing the following process:

i) heat required to decompose carbonates;

ii) heat required to complete other irreversible reactions in clay;

and adding to it the latent heat of the mechanical and combined water measured at a datum temperature 15°—20°C.

HEAT OF DISSOCIATION OF CLAY

It will be observed that in all calculations of thermal efficiency of kilns, it is necessary to determine the heat required to complete 'other irreversible reactions in clay'. The principal heat value involved in the 'other irreversible reactions' is the heat required to decompose the molecule of the true clay mineral at about 600°C. If M is the mass of the clay, then the heat H required to decompose the clay mineral and evaporate the combined water is given by:

$$H = \left(M\frac{a}{100}h\right) + \left(M\frac{b}{100}K\right)$$

where,

a = percentage of combined water

b = percentage of true clay substance

h = total heat of superheated steam at 600°C

K = heat involved in decomposing a unit mass of clay mineral.

Since the greater part of the heat contained in the superheated steam, i.e., $M\frac{a}{100}h$, is recovered by heat exchange with the bricks in the pre-heating and drying zones, only that part of the heat of the steam which leaves the kiln at the waste gas temperature is included in the thermal balance.

The heat involved in the decomposition of the clay molecule (K) depends on the clay fraction (%) and also on the type of clay mineral present. The accurate measurement of this heat is a difficult task where a brick clay with unknown clay mineral content is concerned Noble, loc.cit., has given 33 values for clays of various geological origin but the calculations have been based on the assumption that the residual ignition loss, i.e., total loss-on-ignition — (Mechanical moisture+carbonaceous matter+CO^2 from carbonates) is proportional to the actual clay substance which has again has perhaps been assumed to be kaolinite in all the cases. However, the residual ignition loss need not necessarily be proportional to the true clay substance. This method, therefore, gives only approximate values for the heat required to decompose the clay molecule.

Ramachandran and Majumdar[8] have applied the D.T.A. technique for determining the value of 'K' for brick clays. This technique provides a direct method of determining the heat values associated with the decomposition of the clay molecule and is applicable to any brick clay containing unknown clay mineral or minerals.

EXOTHERMIC REACTION AT 900°C.

While calculating the heat output, a small correction is necessary for the exothermic reaction which takes place between 900°—950° ascribed to a crystalline modification of alumina, viz., Al_2O_3 Thus, if M is the mass of the brick clay and 'b' the percentage of clay fraction, the heat evolved in the exothermic reaction is given by $\left(M\frac{b}{100}k\right)$, where 'k' is the heat evolved per unit mass of clay. MacGee, loc.cit., has applied the differential thermal method for determining the value of 'k' for kaolins and ball clays which has been found to be of the order of 30 — 40 cals. per gramme.

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PRACTICAL STANDARDS

In the actual operation of brick kilns, is always necessary to supply a certain minimum of excess air. The heat loss associated with this amount of excess air is not altogether avoidable and due allowance for this loss should be made in the calculation of the thermal efficiency. Similarly, for practical considerations the waste gas temperature cannot be allowed to fall below a certain minimum value and some amount of heat above the minimum theoretical requirement must unavoidably be lost. Losses due to radiation, convection and conduction from the kiln structure also are not entirely avoidable and certain minimum allowance for this loss must be made while calculating the kiln efficiency. Noble, *loc. cit.*, has suggested that to obtain a standard basis of comparison of the efficiency of the Hoffman and related kilns, a standard allowance of 500% excess air and a waste gas temperature of 100°C should be made. The standard allowable loss due to radiation etc., from the kiln and flue structures has been fixed at 10 lbs. of d.a.f. fuel or 149,000 b.t.u. per ton of brick fired. The values have been deduced on the basis of observations made on the thermal behaviour of 33 kilns.

For obvious reasons these standards cannot be applied to archless kilns such as the Bull's trench. In evaluating the practical standards of efficiency of the Bull kiln due consideration should be given to the minimum practical requirements of this kiln. Being a seasonal industry, the kilns remain idle for about five months in the year. The kiln floor and walls absorb large quantities of water during the monsoon rains and a considerable amount of fuel has to be burnt in drying out the kiln before it can be brought into regular firing order. In order to formulate a standard procedure for comparing the thermal efficiency of different Bull kilns, it is necessary in the first place to carry out a survey on the thermal behaviour of a large number of such kilns operating in different parts of the country. The thermal data obtained in the survey would then provide the necessary basis for fixing the limits of the allowable losses so that the thermal efficiencies could then be compared on the basis of these practical considerations. Investigations on this problem are now in progress at the Central Building Research Institute.

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