Thermal conductivity of some indigenous refractories

K. C. Ray, P. C. Sen, N. B. Sarkar & M. R. K. Rao
National Metallurgical Laboratory, Jamshedpur-

An apparatus for the determination of thermal conductivity of refractory bricks has been described. Thermal conductivities of different types of commercial bricks such as alumino silicates, silica and insulating bricks have been measured. These results are discussed in relation to the porosity and bulk density of the bricks.

Introduction

An apparatus for determining the thermal conductivity of refractory bricks has been fabricated based on the design of Blakeley & Cobb[1] in which a blackened brass plate calorimeter is used to determine the heat transmitted through a refractory brick. The brick is in direct contact with heated chromium plated copper plate below and the calorimeter above. The blackened calorimeter is heated by the conduction of heat coming through the refractory brick. But since the calorimeter is exposed on the surface to the atmosphere it also loses heat by convection and by radiation. The heat lost by convection and by radiation of this calorimeter is calculated as per the method used by Blakely & Cobb. This apparatus is simple and can be fabricated indigenously at a cheaper cost compared to a more sophisticated expensive and elaborate apparatus used for determining thermal conductivity of refractory bricks. The apparatus fabricated has its limitation in that the maximum hot face temperature is 1000°C.

Description of the apparatus

A design[2] of the apparatus as per the design of Blakely and Cobb[1] was fabricated in N. M. L. The thermal conductivity apparatus consists of a rectangular mild steel sheet casing open at the top and lined all round with asbestos board of ¼″ thickness. A layer of firebrick is placed at the bottom over which an insulating refractory slab of 4½″ x 3″ grooved for holding Kanthal heating element is placed. The Kanthal wire in coiled form is embeded in the grooves. A chromium plated copper plate 9″ x 4¾″ is placed over the heater such that it covers the heater and the heater grooves are so designed that the copper plate is uniformly heated. In the present apparatus the chromium plated hot plate is replaced by a silicon carbide slab of 20 mm thickness. The test brick is placed over this slab instead of the copper plate as in the original design. The substitution by silicon carbide slab does not effect the results. The vertical side faces of the test brick is surrounded by sindyano board with vermiculite insulation packing all around. The top face of the test brick is covered by calorimeter consisting of a brass plate of $\frac{1}{4}$" thick x 9" x $4\frac{1}{2}$". In the centre of the brass plate a circular brass disc of $1\frac{15}{16}$" dia x $\frac{1}{4}$" thick is embeded by cutting a groove in the brass plate. The gap between the circular disc and the plate is rammed with asbestos fibre. The top surface of the apparatus is covered with asbestos sheet exposing the brass plate in the middle. To prevent air current, this brick-assembly and calorimeter are enclosed in an open perspex housing kept at the top of the apparatus. The bulb of the mercury thermometer is kept exactly 14" above the brass calorimeter to measure the ambient temperature.

The temperature of the heater is controlled by dimmerstat and an on-off pyrometric controller actuated by chromel-alumel thermocouple embeded in the hot face of the test brick. The ambient temperature is measured by a mercury bulb thermometer reading accurately upto 0.1°C. Three sets of chromel-alumel thermocouple are used; one to determine the hot face temperature of the test bricks, one to measure the temperature of the cold face and one embeded in centre of the circular disc of the calorimeter to measure the temperatures. The thermocouple readings are recorded on a electroflo potentiometric recorder and checked at regular intervals with a sensitive potentiometer. The heater used has a cold resistance 30 ohm and a max. current of 5--7 amps was passed to heat the brick.

Experimental

The test brick of 9" x $4\frac{1}{2}$" x 3" is placed over the heater plate and the calorimeter assembly is placed over the brick. The temperatures of the hot face, cold face of the test brick, the centre disc of the calorimeter and the ambient temperature were measured when the hot face temperature attained stability for atleast 3 hours for the required hot face temperature. Thermal conductivity of a substance by definition is the rate of heat flow through the material per unit temperature gradient i. e.

$$K = \frac{Q/At}{d\theta/dx}$$

Where K=thermal conductivity of the material. Q=quantity of heat flowing in time t, through an area 'A' of the material measured perpendicularly to the direction of heat flow.

$\frac{d\theta}{dx}$ =the rate of change of temperature θ with the length (x) along the line of heat flow, in this case the thickness of the brick.

$$K = \frac{Q}{At} \times \frac{dx}{d\theta}$$

Assuming that the quantity of heat flow is equal to the heat loss by convection and heat loss by radiation from the top horizontal surface, the equation may be reported as

$$K = \text{Heat loss} \times \frac{dx}{d\theta}$$

$$= \frac{(Hc+Hr) \times \text{thickness}}{\text{Hot face temp} - \text{cold face temp}}$$

$$= \frac{(Hc+Hr) \times \text{thickness}}{T_2 - T_1}$$

Where T_1 = cold face

T_2 = hot face temp in °K

Hc = Heat loss by convection.

Hr = Heat loss by radiation.

Heat loss by the brass calorimeter is expected to occur both by convection of the air above the furnace which is assumed to be uniform within the draught guard box and by radiation of the calorimeter disc which is exposed to the surface. For a horizontal plane surface facing upwards heat loss by convention Hc is calculated from the following formula.

$$Hc = 2.19\ Tp - Ta)^{1.25}\ \text{Cals/Sq.m/hr}$$

Where Tp is the temperature of the circular disc and Ta the ambient temperature of the air in °K.

Heat loss by the same surface by radiation Hr of the brass calorimeter in air is calculated by the following formula.

$$Hr = 4.82\left[\left(\frac{Tp}{100}\right)^4 - \left(\frac{Ta}{100}\right)^4\right] \text{Cals/Sqm/hr}$$

All the bricks were placed on their 9″ x 4½″ face to give a proper sitting both on the heater as well as on the calorimeter. For embedding the thermocouples, grooves were made and care was taken to see that the thermocouples junctions were in centre of the hot and cold faces of the brick. A calorimeter thermocouple was embeded in the centre of the circular disc of the calorimeter. The current is now switched on to give maximum current to raise the hot face temp to the required value and the hot face temperature is controlled by the temperature controller.

Readings of the cold face, calorimeter, and air temperature are taken at regular intervals (say ½ hr) after the air temperature was constant.

Thermal conductivity value of different dense bricks like, magnesite, high alumina and alumino silicates and insulation were determined using this apparatus.

Results and discussion

The thermal conductivity of various dense refractory bricks are reported in Table I. The values are comparable to those reported in the literature. It was noted that i[illegible] the c[illegible] of dense alumino-silicate bricks, thermal conductivity increases with the increase of alumina content of the brick, apart from the effects of bulk density and porosity.

Table II illustrates the thermal conductivity, bulk density and porosity of the different types of insulating bricks made from different raw materials such as fireclay, silica, vermiculate and wollastonite (calcium silicate). It was observed that the thermal conductivity of porous bricks is directly related to the porosity or bulk density of the bricks irrespective of the type of raw materials from which it was manufactured when the porosity of the bricks ara more than 50%. This is illustrated in Fig. 1, 2 and 3. The relative dependence of the thermal conductivity of porous insulating bricks shows that thermal conductivity decreases as the porosity of the insulating brick increases. Fig. 2 illustrates the variation of log of thermal conductivity of insulating bricks with porosity. The logarithm of thermal conductivity bears straight line relationship with the porosity (50% to 85%) of the insulating bricks. Similarly Fig. 3 illustrates that the logarithm of thermal conductivity increases linearly with the increase in bulk density. It seems that in the case of insulating bricks of porosity above 50%, the effect of type of raw material such as fireclay, silica, vermiculate etc., have minor influence on the thermal conductivity values. However, if the porosity of the brick

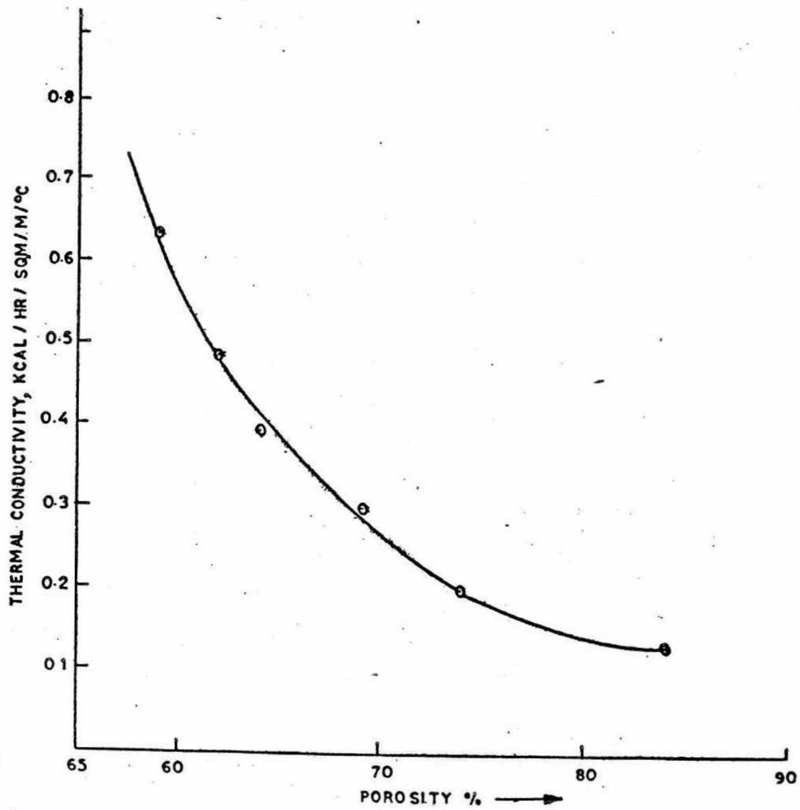

Fig. 1 Relationship of thermal conductivity with porosity of Insulating bricks

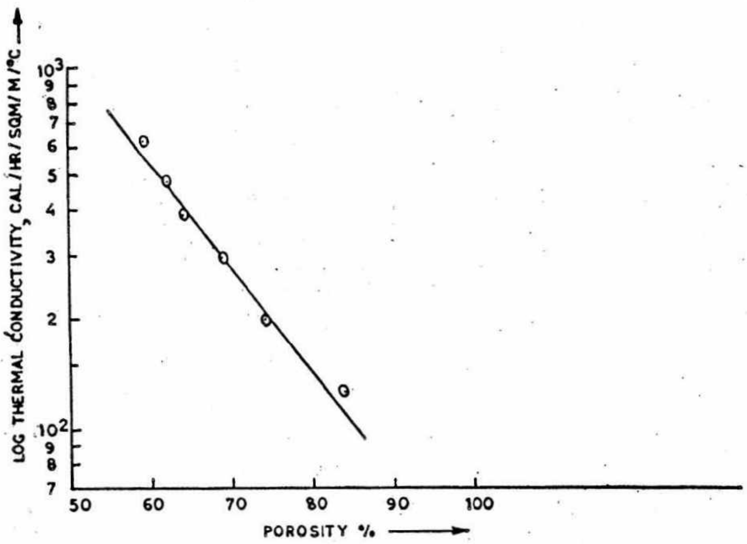

Fig. 2 Variation of thermal conductivity with porosity in insulating bricks

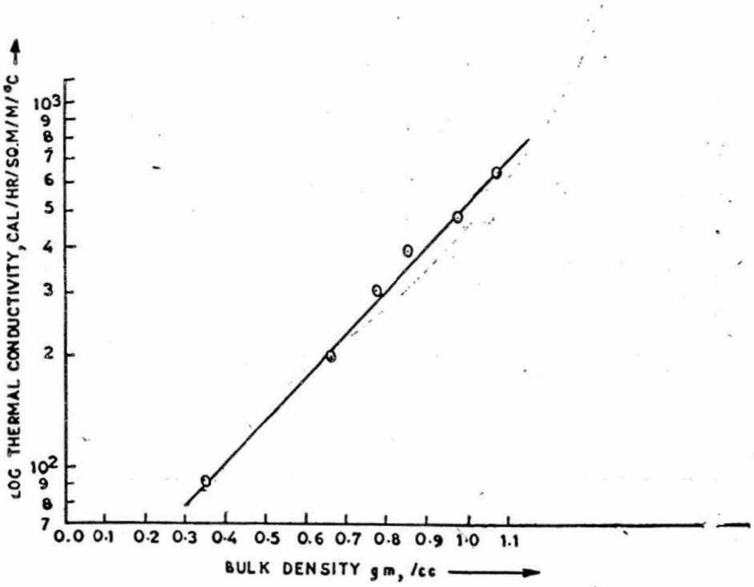

Fig. 3 Variation of thermal conductivity with bulk density in insulating bricks

is less than 50% this relationship does not seem to hold good as some of the results on brick with 30% porosity do not conform to this relationship.

Conclusion

An apparatus based on the design of Blakeley & Cobb was found suitable for determining thermal conductivity of refractory bricks below a hot face temperatures of 1000°C. For insulation bricks having a porosity of 50% and above, the thermal conductivity is governed mostly by the porosity of the bricks rather than the type of bricks as is shown by the present study. For dense alumino silicate bricks the thermal conductivity appears to increase with the increase of alumina content.

Acknowledgement

The authors'—thanks are due to Prof. V. A. Altekar, Director, National Metallurgical Laboratory for his kind permission to present the paper and for publication.

References

1. T. A. BLAKELEY & J. W. COBB., "An apparatus for testing heat insulating bricks". Trans. Jour. Soc. Chem, Ind. March 11, 1932 pp. 83T—89T.

2. H. P S. MURTHY, & T. K. GANGADHARAN, "A comparative study of the ASTM Thermal conductivity and the Blakeley Cobb Apparatus as instruments for routine measurements of thermal conductivity of Refractories". NML Tech. Jour. May 1966, Vol. VIII. No. 2, pp 15—19.

TABLE I—Porosity, bulk density, app. spr. gr. and thermal conductivity of the various dense bricks.

Marking of the brick	Hot face temp °C	Cold face temp °C	Mean Temp °C	Porosity %	B. D. gm/cc.	App. Sp. Gr.	Thermal conductivity KCal/hr/sqm/m/°C
Acid resistance	800	357	579	10.39	2.196	2.45	1.914
High grog	800	381	590.5	17.5	2.31	2.78	1.658
Sillimanite	800	412	606	18.73	2.48	3.04	1.783
Kyanite	800	337	568	23.1	2.302	2.99	1.602
High alumina 70	800	482	641	23.45	2.67	3.52	1.776
High silica 70	890	350	575	27.1	2-445	3.32	1.195
High alumina 50	800	405	602	27.9	2.52	3.32	1.603
High heat duty	800	408	604	28.53	2.02	2.82	1.572
Magnesite	800	551	175.5	20.77	2.79	3.522	4.171

TABLE II—Porosity, bulk density, app. sp. gr. and thermal conductivity of the insulating brick.

Marking of the brick	Hot face temp °C	Cold face temp °C	Mean temp. °C	Proosity %	B. D. gm/cc.	App. Sp. Gr.	Thermal conductivity KCal/hr./sq.m/m/°C
Light wt insulating	800	261	230.5	33.8	1.66	2.51	0.584
Fireclay insulation	800	293	546.5	58.7	1.07	2.52	0.628
Hot face insulation	800	249	524.5	62.3	0.97	2.58	0.476
Silica insulation	600	201	400.0	63.5	0.85	—	0.387
Silica insulation	800	214	507	69.2	0.77	2.42	0.304
Vermiculite insulation	800	155	478	73.9	0.67	2.562	0.199
Wollastonite insulation	650	111	375	84.65	0.35	2.273	0.128
Wolastonite insulation	250	48	149	84.65	0.35	2.273	0.09