Technology Section

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Measurement of Thermal Conductivity of Marble Powder by Spherical Shell Method

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An apparatus, designed and developed for the measurement of thermal conductivity 'K' of powdered material by spherical shell method, has been described. Extrapolation of straight line graph of K-values against varying densities of different mesh sized powder material gives K-value of lumps of marble. It does not give K-value of solid material because the density of compressed powder can not be equivalent to the density of natural marble. K-values of different mesh sizes marble powder have been determined and results are discussed with reference to the data already available in literature.

Key Words: Thermal conductivity, Spherical shell method, Marble powder

Introduction

Efficient thermal insulation is getting increased importance with ever increasing interest in energy conservation. A reasonable amount of fuel or electrical energy can be saved by using appropriate heat insulating materials with optimised thickness for thermal insulation of buildings, refrigerators, furnaces, ovens, etc. In summer season, the air conditioners fitted in rooms, with walls and ceiling (not properly insulated), frequently breakdown causing wastage of a large amount of electrical energy. The efficiency of the air conditioner may be improved by using appropriate heat insulating material in the walls and ceilings of the rooms.

Thermal conductivity data of heat insulating building material (West 1986 - 87) is unsatisfactory in the sense that: (i) the accuracies are poor and some times even unknown, (ii) the values for different temperatures are not available and (iii) the values for composite material can not be used without reservations. The Semi-Dynamic method (Lee's Disc method) (Worsnop and Flint 1941) gives error and it is very inconvenient to note down the readings in a room of ambient temperature at about 35 °C, because of continuous flow of high pressure steam to perform the experiment. The method can only be applied to the materials that can be shaped into 'Discs'. This method is limited to measure K-values of heat insulating materials ranging from 0.1 to 1.0 WmK^{-1}. Thermal conductivity of solid materials having K-values from 1.6 to 2.5 WmK^{-1} can not be determined by this method. The elaborated NBS method (ASTM C-177 1963; C-518 1985) and the transient Hot-Wire technique (DIN V-51046; JIS R-2618; Batty *et al* 1981) are precise methods, but the values obtained by these two methods have to be reconciled.

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Accurate values of thermal conductivity play important role in the efficient design of heat exchange equipment in which powder or lumps are used as heat insulating material. This paper describes the experimental set-up of an apparatus designed and fabricated for the measurement of K-values of materials in powder or lump such as sand, asbestos, clay, etc. at different temperatures with reasonable accuracy. The apparatus works on the principle of radial heat conduction from a spherical heat source, surrounded by the material under test. The advantage of this apparatus is that the total heat is consumed in heating the sample and there is almost no heat loss as compared with the heat losses in Lee's Disc method, where guard rings have been employed to minimize heat losses (ASTM C-177 1963).

Theory. When a spherical source of heat is applied to a surrounding powder material of thermal conductivity 'K', then isothermal spherical layers are formed. Let 'r' be the radius of an arbitrary sphere and 'T' be its temperature, the amount of heat 'Q' supplied to the specimen by conduction is given by:

$$Q = -4\pi r^2 K \frac{dT}{Dr}$$

where 'dT' is the small rise in temperature and 'dr' is the thickness of the hollow sphere of the specimen. This is Fourier equation of Thermal Conductivity in general which can be written as:

$$dT = -\frac{Qdr}{4\pi r^2 K}$$

On integration

$$T = \frac{Q}{4\pi r K} + A$$

where 'A' is constant of integration.

Now considering two concentric spheres of radii 'r_1' and 'r_2' of the same specimen, having temperatures T_1 and T_2 respectively, we get

$$T_1 = \frac{Q}{4\pi r_1 K} + A$$

$$T_2 = \frac{Q}{4\pi r_2 K} + A$$

On subtracting

$$T_1 - T_2 = \frac{Q}{4\pi K} \left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

From which 'K' can be worked out as:

$$K = \frac{Q}{4\pi} \quad \frac{r_2 - r_1}{r_1\, r_2\, (T_1 - T_2)}$$

Materials and Methods

The apparatus consists of two hollow brass spheres (Saha and Srivastva 1950) as shown in Fig. 1. The internal sphere S_1 has inner diameter 40 mm and outer diameter 50 mm whereas the external sphere S_2 has inner diameter 130 mm and outer diameter 150 mm. The two spheres are strictly concentric.A spherical heating coil 'H' is placed at the centre of the inner sphere S_1 to provide uniform heat in all directions and electric energy is supplied at a constant rate from a stabilized power source. The leads of the heating coil come out through a sealed rigid ceramic tube fixed in S_1 and S_2. Each sphere comprises of two hemispheres such that they can be opened and closed as shown in Fig. 2. In order to measure the temperatures of the isothermal layers of the powdered specimen under test at radial distances r_1 and r_2, two thermocouples Th_1 and Th_2 are employed assuring that the thermocouples are located within

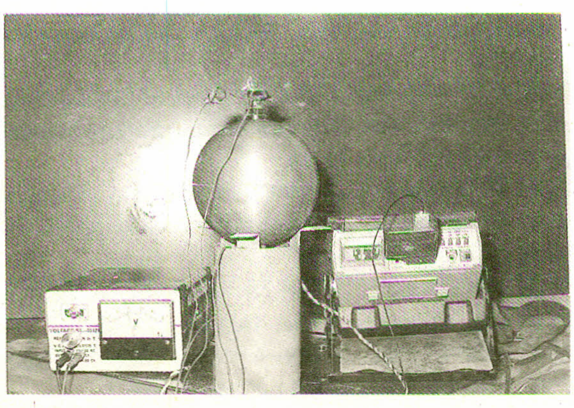

Fig.1. Photograph of the spherical shell power supply and digital thermometer.

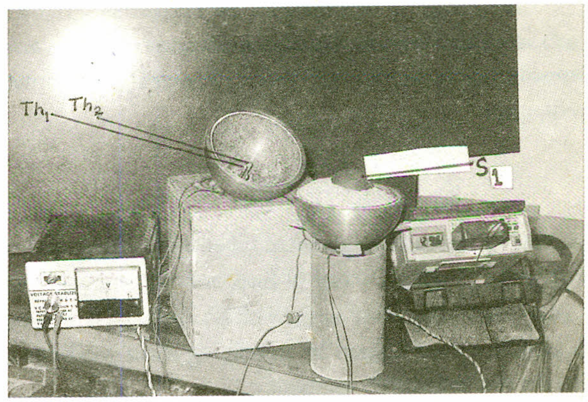

Fig.2. Photograph showing the internal sphere S_1(close) and external sphere S_2(open) and thermocouples Th_1 and Th_2 with test specimen between the space S_1 and S_2.

the specimen (Joblonski and Wnetrzewski 1983). When the heating coil is switched 'on' through a stabilized power supply, uniform heating of internal sphere S_1 starts thereby heating of the specimen under test uniformly and we get isothermal spherical layers of the specimen (Ignaszak 1983). When steady-state is reached, the temperatures T_1 and T_2 are noted and heating is switched 'off'. This apparatus uses only powdered samples. The lumpy samples need to be ground to various mesh sizes (Golovchan 1981) and K-value data obtained for the different graded samples is graphically extrapolated to get K-value of the sample in the lump form.

In order to determine the K-value of marble powder, the solid material was powdered and sieved through different mesh sizes, designated as 100, 80, 50, 13 and 8, and apparent density of each sample was measured as 1.08, 1.15, 1.28, 1.45 and 1.6 gm cc^{-1} respectively. The samples were dried in an oven to make them moisture free. The powder sample of a given mesh size was loaded in the space between the two spheres assuring that there was no cavity, voids or gas pocket and there was a good thermal contact. Two thermocouples Th_1 and Th_2 were mounted at radii r_1 and r_2 to measure the temperatures T_1 and T_2. The space between the thermocouples (r_2 - r_1) determined the annular thickness of the test specimen between radii r_1 and r_2 of the two isothermic spherical layers giving temperature T_1 and T_2 respectively.

Each sample was heated through spherical heater 'H', (17.8 Watts) placed at the centre of the inner sphere S_1 by supplying electric energy at constant rate, i.e., a steady current of 0.87 Amperes at a potential difference of 20.5 Volts through the heating coil. When steady-state was reached, the temperatures T_1 and T_2 were recorded and heating coil was switched 'off'.

The experiment was repeated for other samples with different mesh sizes by keeping radii of arbitrary spheres r_1 and r_2, current 'I' and voltage 'V' unchanged. Thermal conductivity 'K' of each sample of a given density (mesh size) was determined by substituting the values of I, V, r_1, r_2, T_1 and T_2, in the following equation.

$$K = \frac{IV}{4\pi} \quad \frac{r_2 - r_1}{r_1\ r_2\ (T_1 - T_2)}$$

Three sets of measurements were taken for each sample of a given mesh size.The K-value of three samples for each mesh size was found very close to each other. Average K-values of each sample was obtained by averaging three readings obtained for the respective samples.

Results and Discussion

The average K-values of marble powder obtained for various densities by Spherical Shell method are given in the Table 1. The K-values of different mesh sizes powdered marble were determined and plotted (Fig 3).

Figure 3 shows that the K-values plotted against the apparent density is a straight line. As the density of the powder goes on increasing from finer to coarser size, the K-value also increases. The straight line graph obtained by joining the K-values of different mesh sizes marble powder indicates that the K-values are directly proportional to the density. On extrapolation of the graph, to determine K-value of lumps form of the specimen with density 1.8, it gives K-value as 0.72 WmK^{-1}. It has also been observed that K-value of solid piece of the specimen cannot be determined by extrapolation of this graph because the powder can not be compressed so much that the density becomes equivalent to the density of natural marble.

Conclusion

Thermal conductivity of heat insulating materials in powder or lumps form can be determined by this technique. The density of powdered material is directly proportional to the K-value of the material. The straight line graph (Fig 3) varifies this relation and indicates that the accuracy of K-value of marble powder determined for various grain sizes are reliable.

Table 1
Thermal conductivity 'K' of marble powder with different grain sizes at temperature 90°C.

Sample no.	Grain size mesh no.	Density gm cc^{-1}	K-values W mK^{-1}
1.	100	1.08	0.23
2.	80	1.15	0.28
3.	50	1.28	0.36
4.	13	1.45	0.48
5.	8	1.60	0.58

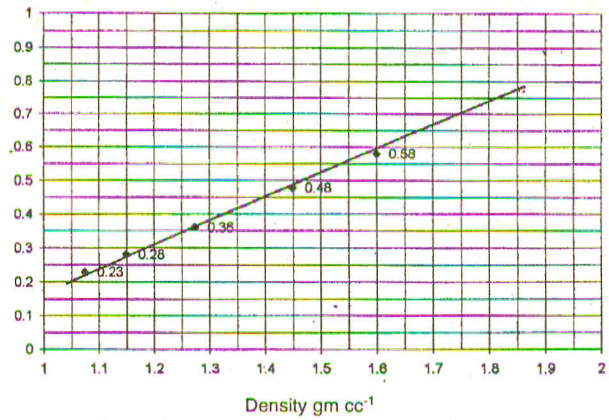

Fig 3. Graph showing the K-values of the powdered material plotted against different grain sizes (density) of the material.

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