ON THE THERMAL CONDUCTIVITY OF INDIGENOUS INSULATING SUBSTANCES

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ABSTRACT. The present communication reports on the measurement of thermal conductivities of substances like Glass, Mica, Tintex, Masonite, Beaver, Plywood, Asbestos, Saw-dust, Straw, Husk, Jute, Cocoanut-fibre, Kapok, etc., with the aid of a handy apparatus constructed on the well-known principle of "wall" method.

INTRODUCTION

At the present time India is greatly interested in the refrigeration industry for its application to home, both in household refrigerating machines and in comfort cooling, and also in other applications of air-conditioning, *viz.*, in auditoriums, industries, cold storage ware-houses, etc. With this development of comfort cooling the refrigerating engineer has to face with problems arising out of losses due to heat leakage. Let us take, for example, the case of food preservation. The refrigeration of food consists mainly of removing heat from the food and keeping the outside heat away from it. Foods which have been cooled by refrigeration will absorb heat again unless care is taken to keep heat away from coming in contact with them. This action takes place because heat flows from places of higher temperature to places of lower temperature. Thus heat is constantly passing into a refrigerated compartment from the outside. The refrigerating unit must have enough capacity to remove this heat leakage along with the heat that is admitted when the doors are opened and closed and the heat that is brought in with the warm foods.

Extended tests on household cabinets indicate that the total cooling load on the condensing unit may be apportioned as follows:

Opening or closing doors	5%
Cooling the foods and liquids	18%
Leakage through insulation, frames and joints	77%

It is evident from this that the proper insulation of a cabinet is an important item in keeping down operating costs to a reasonable figure. And, in fact, no insulation exists which can keep out all the heat; but there are certain kinds of insulating materials which are more effective than others. The present report gives the results of an investigation of the thermal conductivity of indigenous Indian materials that may be suitably used as heat-insulating bodies. The apparatus designed and constructed is a handy one and with its aid the thermal conductivity of any substanc can be determined within 4 hours.

DESCRIPTION

We now describe the technique developed for testing a large number of materials of low conductivity, of which relatively small samples can fairly be taken as representative of the parent material. The apparatus designed is a modification of the 'plate' or 'wall' method to which the standard equation defining the conductivity, 'k,' shown by the relation

$$Q = kAt\,\frac{\theta_1 - \theta_2}{d}$$

is directly applicable. Here, 'Q' is the quantity of heat which, when the steady state is reached, passes normally in time 't' through a material of cross-section 'A' and thickness 'd,' the faces of which are maintained at temperatures θ_1 and θ_2.

The hot face is a copper block and is heated electrically. The cold face is a similar copper block and the material to be tested is sandwiched between these two faces. The heater is made by winding Constantan wire (No. 32 S. W. G.) of total length 100 inches on a mica sheet. This is placed between two copper blocks, each 4 in. sq. and 0.22 in. thick, the blocks being insulated from the heater by two mica sheets. The sample to be tested (when available in slab form) is cut to the same size and of suitable thickness and is placed by the side of one of these two copper blocks. Another similar copper block is placed on the other side of the sample. The exposed surfaces of this whole arrangement are varnished so as to give them the same emissivity. This assemblage is then held as a compact body with their surfaces in vertical position and housed in a wooden box with the lower surfaces resting on two wooden knife edges covered with asbestos. Three holes are drilled right up to the centre of all the three blocks from their top-edges for the insertion of the thermo-couple junctions required for the measurement of their temperatures. The arrangement is shown in Fig. 1.

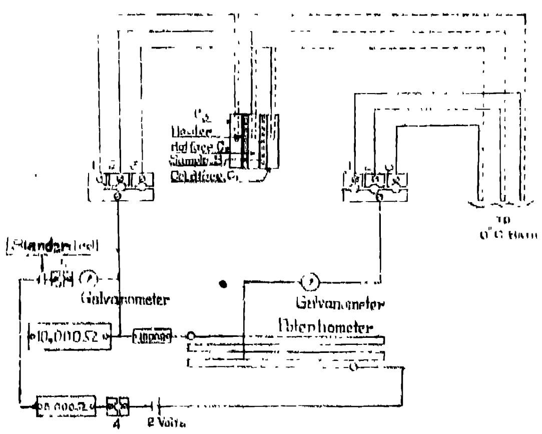

FIG. 1

EXPERIMENT

The experiment is started with the sample kept as described above. To ascertain the temperatures of the copper blocks directly, the thermo-couples are calibrated in degrees-centigrade with the help of a potentiometer by usual methods. The reference junctions are kept at 0°C. To ensure good thermal contact of the other junctions with the copper blocks mercury is poured into the three holes. Electric current is now passed into the heating grid and the electrical energy spent in heating the heater is obtained by measuring the current with an ammeter reading .0.02 amp. per scale division and the potential drop across the heating coil with a voltmeter reading 0.5 volts per scale division. The steady state can be attained in times from 90 to 100 minutes and often 2 hours.

The measurement of the surfaces and edges of the blocks as well as the sample presents no difficulty. But some difficulty arises regarding the measurement of the thickness *d* in case of compressible materials like fabrics, saw-dust etc. and for these the following device has been adopted.

Thermal conductivity of plywood is first determined carefully. It is then cut as shown below (see Fig. 2) and is pasted between the hot and cold faces with Duco cement.

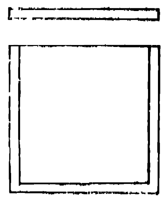

FIG. 2

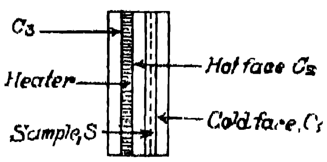

FIG. 3

The sample to be studied is placed in the hollow space left within. The quantity of heat flowing through the sample is equal to the heat lost from the exposed surface of the block C_1 (Fig. 3) minus the heat flowing through the plywood. Knowing the difference of temperature, area, thickness and conductivity of the plywood frame, the heat flowing through the plywood frame is calculated. In this way the thickness, *d*, of such samples is made fixed and the conductivity for a definite density of packing is known.

THEORETICAL CALCULATION

A simple sketch of the arrangement is given here (see Fig. 3).

Let H = rate of energy supplied to the heating coil.

h = heat loss per sq. cm. for 1°C. excess of temperature of the blocks over that of the surrounding.

$\theta_{1,2,3}$ = the excess of temperatures of C_1, C_2 and C_3 over that of the surrounding.

d = thickness of the substance S.

$A_{1,2,3,s}$ = areas of the copper blocks as well as of the substance across which heat is flowing.

$a_{1,2,3,s}$ = areas of the edges of C_1, C_2, C_3 and of substance S.

Now heat that is received per second by the block C_1 and given up to the air is

$$(A_1 + a_1)h\theta_1 \qquad \ldots \quad (1)$$

and the heat that is received per second by the sample S and given up to the air from its edges and passed on to C_1 is

$$(A_1 + a_1)h\theta_1 + ash\frac{\theta_1 + \theta_2}{2}. \qquad \ldots \quad (2)$$

If k is the thermal conductivity of the sample S, then the heat flowing through this per second is

$$Ask\frac{\theta_2 - \theta_1}{d}. \qquad \ldots \quad (3)$$

Assuming that the heat flowing through the substance S is the mean of the quantities of heat flowing in and out of the substance, *i.e.*, the mean of the equations (1) and (2), it is evident that

$$Ask\frac{\theta_2 - \theta_1}{d} = (A_1 + a_1)h\theta_1 + ash\frac{\theta_1 + \theta_2}{4} \qquad \ldots \quad (4)$$

giving a relation between k and h.

Further the total heat imparted to the system must equal that given up to the surrounding air from all the exposed surfaces. Hence

$$H = (A_1 + a_1)h\theta_1 + ash\frac{\theta_1 + \theta_2}{2} + a_2h\theta_2 + (A_3 + a_3)h\theta_3. \qquad \ldots \quad (5)$$

Thus (5) determines h and so, from (4), k can be obtained, as all other quantities in (4) are measured experimentally.

The actual values for the conductivity of certain insulating materials as obtained by the above calculation are given in the table.

CONCLUDING REMARKS

The problem of maintaining efficiently the desired low temperatures in refrigeration units requires a careful study of the available insulating materials. The investigation so far carried out is only a part of this study. Besides the property of thermal conductivity of different materials, the following other properties must also be studied for the selection of an insulator :—

(1) *The structural strength.*—Some insulating materials lend themselves readily to various types of construction and are easily handled under all circumstances. This strength is generally obtained by the use of wood or steel framework to hold or contain the insulation. And the slab forms of insulation provide a stronger, more sturdy and economical type of construction than the powdered

TABLE

Conductivity of some insulating materials

No	Sample	Nature of sample	Density in lbs /c.ft.	Humidity	Thermal conductivity in (B.T.U.) $(in.) (ft.)^{-2} (hr.)^{-1} (°F.)^{-1}$
1	Glass	Crown glass in slab form of thickness 0.197″	164.2	85%	7.54/162°F.
2	Mica	In the form of sheet of thickness 0.0085″ to 0·03″	...	72%	Varying from 2.82 to 4.05/145°F
3	Tintex	Trade product in board form, 0.511″ thick	19.2	96%	0.63*/167°F.
4	Masonite	Trade product in board form, 0.523″ thick	18.2	70%	0.65*/161°F.
5	Beaver	Trade product in board form, 0.503″ thick	18.7	66%	0.64*/161°F.
6	Plywood	Three pieces compressed into board shape of thickness 0 165″	44.4	83%	1.12/136°F.
7	Asbestos	Fibres compressed into board form, 0.157″ thick	52.4	83%	0.81/174°F.
8	Saw-dust	Obtained from Teak-wood, finely grained and packed in the form of a slab, 0 165″ thick	27.1	84%	0.66/158°F.
9	Straw	Cut into small pieces of average length—5/8″ and packed in the form of a slab, 0.165″ thick	7.8	73%	0.24/165°F.
10	Husk	Coarsely powdered and packed in the form of a slab, 0.165″ thick	17.6	93%	0.31/143°F.
11	Jute	Fibrous structure, loosely packed in the form of a slab of thickness 0.165″	9.0	80%	0.25/154°F.
12	Cocoanut fibre	The fibres are packed loosely in the form of a slab of thickness 0.165″	8.0	70%	0.28/154°F.
13	Kapok	Fine tubular fibres obtained from sundried pods of *Simul* trees growing in the country and loosely packed in the form of a slab of thickness 0.165″	3.0	88%	0.17/170°F.

* These are commercial products and the thermal conductivity values we have obtained for them are higher than the values given by their manufacturers. These higher values may partly be due to the fact that the experiment is carried out in an atmosphere where the percentage of humidity is sufficiently large.

forms. So, investigation is necessary for transforming these powdered samples into cake forms with the minimum change in their k values.

(2) *The weight.*—This becomes a deciding factor when the application of insulation to railroad refrigerator cars, marine works, etc., is considered.

(3) *Selection of different insulators.*—Insulators derived from vegetable and animal sources are always subject to decomposition in course of time resulting in the development of odours. Odours are also developed on account of the growth of mould which takes place when the insulation is affected by the presence of moisture. There are many articles of food which absorb odours when exposed to them and this is really unsanitary. Hence the development of odours must be avoided.

(4) *The resistance to vermin.*—Several forms of vermin regard insulators of vegetable origin as their food and in a tropical country like that of ours the presence of various forms of vermin is not uncommon. Hence these insulators are to be specially protected.

(5) *Resistance to the absorption of moisture.*—Moisture in an insulation not only increases the thermal conductivity of it but also has a destructive effect. Changes in temperature between the interior and exterior surfaces of the insulation have a breathing action resulting in the condensation of moisture inside and even on the exterior in very humid climates. This causes dripping and odours, thus allowing the formation of mould. So, the insulation must be properly sealed against moisture.

(6) *Resistance to fire.*—This is not a deciding factor in the choice of an insulator, but in some applications, such as for fire-proof ware-houses, this characteristic is important.

It is evident from what has been said so far that the insulation cannot be chosen on the basis of only one desirable characteristic. On the other hand, preference should be given to that insulation which has the greater number of desirable qualities with respect to some particular application. And unless all these properties of the materials which have been investigated so far are studied carefully, we cannot be definite about the right selection of insulation which is so essential for the efficient production of household refrigerating units and installation of self-contained air-conditioning plants.

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ERRATA

Study of Electrolytic Dissociation in Iodic Acid by Raman Effect—By N. Rajeswara Rao :—

In Plate V (facing page 76), *for* 1N *read* 6N ; *for* 6N, *read* 1N.

Propagation of Sound in Liquids and Viscosity—By G. Suryan :—

Page 77, eqn. (2) *for* $\log_{10} = [\ \log_{10}(\eta \times 10^5)]\, 1.2$

read $\log_{10} v = [\ \log_{10}(\eta \times 10^5)]\, 1.2$

Page 78, line 19, *for* 113 (2,3) *read* 1113 (23).