DETERMINATION OF THERMAL CONDUCTIVITY OF LOCAL INSULATING MATERIALS

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RINGKASAN

Tujuan pengajian ini adalah untuk menentukan nilai kealiran haba bagi bahan-bahan penebat tempatan. Olih kerana kealiran haba hanya boleh diperolehi dengan cara ujikaji, satu radas ujikaji yang dikenali sebagai 'guarded hot plate' telah direkakan di dalam makmal. Kealiran haba bagi empat bahan-bahan penebat tempatan ditentukan dengan menggunakan radas tersebut. Keputusan yang didapati adalah agak memuaskan. Bagaimanapun, ada terdapat sedikit kekurangan dalam radas dan pada ujian yang telah dilaksanakan.

ABSTRACT

The aim of this study is to determine the thermal conductivity of locally available insulating materials. Since the thermal conductivity can only be obtained by experimental methods, an experimental rig known as the guarded hot plate was fabricated in the laboratory. The thermal conductivity of four locally available insulating materials was determined using this apparatus. The results obtained were acceptable. However the apparatus and the actual test had a few short comings.

Introduction

The by-products from local factories such as waste foam from packaging material, waste hard rubber, corrugated cardboard, various types of wood, sawdust, waste sheet metals and the like have good insulating properties. Hence, these materials could be used in thermal insulation applications.

The minimisation of wastage is as important as finding new sources of fuel. Therefore as more commercial processes come into operation, the prevention of unwanted heat leaks has received increasing attention, not only to reduce running costs but also to simplify the stabilisation of temperatures over large volumes.

There is no way of knowing the thermal conductivity of a material except by determining it experimentally. Established data of conductivity values for various insulating materials may be available but the thermal conductivity of many substances is sensitive to such a large number of effects, that it is preferable to resort to a direct experimental determination of thermal conductivity rather than referring to published data. This is especially necessary for our case as the local materials to be selected would differ considerably both in composition and moisture content from those which published data of conductivities are based on and this has considerable effect on the actual thermal conductivity value of the material.

THE TEST APPARATUS

Guarded Hot Plate

A guarded hot plate apparatus was constructed in the laboratory for the purpose of measuring thermal conductivity of low thermal conductivity insulations. The principle of the guarded hot plate is simple and based on the steady-state heat transfer between a warm an cold plate. The thermal conductivity of an insulation can be investigated by placing the material between the plates. The guarded hot plate method of determining the thermal conductivity of insulating, building and other materials is generally accepted as the most precise procedure. It has been standardised by many countries such as in the United States (ASTM Test C 177 – 71), in Great Britain (B.S. 874: 1965) and in Germany (DIN 52612).

Construction

The general features of the apparatus are as shown in figures 1 and 2. The plates are square and the term guarded hot plate is applied to the entire assembled apparatus including the heating unit, the cooling units and edge insulation. Square heater plates made of two copper plates are heated by a uniformly distributed resistance wire wound on asbestos board placed between the plates and electrically insulated from them with micanite sheet. The central heater is surrounded by a square ring of similar construction which is independently maintained at the same temperature as the adjacent surfaces, so that ideally no heat leakage occurs from source or sink, thus ensuring heat flow from the central heater is accurately in the direction in which thickness is measured. This arrangement ensures that the rate of heat flow from the source used in the computation of thermal conductivity for the specimen is equal to and not less than that actually passing through the specimen. With heater and guard-ring plates of metal, the heater is separated by about 2mm from the guard so as to prevent any conduction of heat from one to the other. This gap is assured by the insertion of asbestos paper.

Two pieces of the sample of insulation under test are made approximately the same size as the heater and guard combined. They are

placed symmetrically on each side of the heater. Two water-cooled plates of copper are placed to maintain a lower temperature on one side of each sample. The entire apparatus is insulated on the edge with loose or blanket insulation so that the resistance to heat flow outward is two or three times that of the sample in the direction of normal heat flow. In operation, the guard is kept at essentially the same temperature as that of the heater by heating arrangement from separate power source and rheostats as in Figure 3, to prevent appreciable flow of heat from one to the other. This is accomplished in the experiment by suitable adjustment of the rheostats. As the thermal conductivity values of the insulating materials to be tested are expected to be less than 0.0173 watts/cm°C, then under ASTM standard test recommendation, the surface temperatures of the test specimens can be determined by means of thermocouples attached directly to the hot and cold plates.

Dimensions and Materials used

The dimensions adopted are as follows:

Central section of heating unit	150 mm square
Width of guard area around heating unit	75 mm
Gap width	2 mm
Thickness of hot plate	4.76 mm
Cold plate	300 mm square
Thickness of cold plate	4.76 mm
Cooling tubes	12.7 mm dia.

Materials used:

Hot plate	Copper
Cold plate	Copper
Cooling tubes	Copper
Central heater	Asbestos board with Nichrome-V wire as heating element.
Insulating sheet	Micanite.

Results

Tests were carried out on 4 specimens.

(i) Laminated asbestos.
(ii) Polystrene.
(iii) Plywood and
(iv) Composite fibre glass.

The thermal conductivity of the material is determinded by the formula as derived in Appendix A. Figure 4 shows the graph of temperature vs time plotted for polystrene.

The result can be tabulated as follows:

Material	Bulk density kg/m^3	Thermal conductivity W/mK
Laminated asbestos	284	0.098
Polystrene	21	0.095
Plywood	2720	0.173
Composite fibre glass	1500	0.105

Validity of results:

The tests carried out determine the thermal conductivity of insulating materials at ambient conditions. Under ambient conditions various factors affect the thermal conductivity value such as air trap, dirt, density and moisture content. Therefore, although standard values from books of tables are available, it is not possible to make direct comprision with the test values. It is observed, however, that the test values, although of the same order of magnitude as the standard values, are higher than the values available from books.

Errors Generated

Thermal conductivity measurements made by the guarded hot plate method are subjected to error from heat loss by convection at the exposed edges of the samples.

Errors are also generated due to the form of construction of the apparatus and can be divided into three factors:

(i) errors due to the actual existance of the gap.
(ii) errors due to imperfect side insulation
(iii) errors due to any temperature difference across the gap.

Short comings

The apparatus made in the laboratory had a few practical defects such as unevenness of plates, imperfect contact between various plates and imperfect side insulations. These are due to methods of fabrication adopted utilising the facilities available in the laboratory. As for the actual test, it was observed that it took as long as five to six hours for steady-state conditions to be reached.

Conclusion

The guarded hot plate apparatus provides a simple method of determining the thermal conductivity of sheet insulators. The values obtained are acceptable and can be used for selection of best insulating material. It is hoped to be able to prepare a table of values of thermal conductivity of local insulating materials.

Acknowledgements

The author wishes to acknowledge the work done by his students Kang Tai Meng and Idris bin Abas in the fabrication of the test apparatus and the performance of the tests.

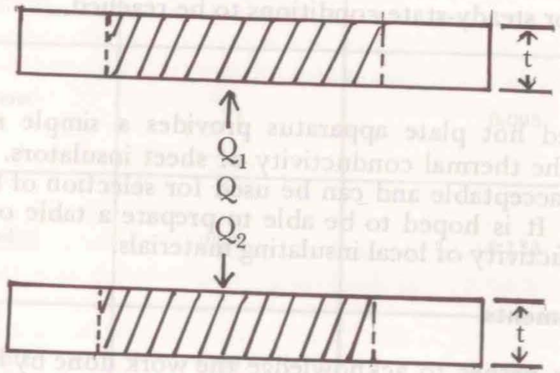
REFERENCES:

KANG TAI MENG: 'Fabrication of guarded hot plate for determining thermal conductivity of rigid insulators to be used in the construction of an ice-box'. B.E. thesis Universiti Teknologi Malaysia, March 1979.

IDRIS BIN ABAS: 'Insulation properties of materials', B.E. thesis, Universiti Teknologi Malaysia 1979/1980.

APPENDIX A
ANALYSIS OF HEAT TRANSFER IN THE GUARDED HOT PLATE.

It is assumed that heat flows only in one direction, i.e, unidirection. The strength of heat transfer or heat flux (W/A) from central heater must be equal to the guard ring heater. Therefore, no heat will be transferred in horizontal direction.



Equation of heat transfer of single flat homogeneous insulating material is given by

$$Q = k \times A \times \frac{dT}{t}$$

The total heat transfer can be divided into two:—

$$Q_1 = k_1 \times A_1 \times \frac{dT_1}{t_1}$$

$$Q_2 = k_2 \times A_2 \times \frac{dT_2}{t_2}$$

where Q_1 and Q_2 are the upward and downward of heat transfer respectively.

Therefore, total heat transfer is sum of upward and downward heat transfer:—

$$Q = Q_1 + Q_2$$

$$= k_1 \times A_1 \times \frac{dT_1}{t_1} + k_2 \times A_2 \times \frac{dT_2}{t_2}$$

Since $k_1 = k_2$

$A_1 = A_2$

$dT_1 = dt_2$

$t_1 = t_2$

Total heat transfer,

$$Q = 2 \times k \times A \times \frac{dT}{t}$$

From above equation, thermal conductivity k can be written as follows:—

$$k = Q/2 \times \frac{t}{A \times dT}$$

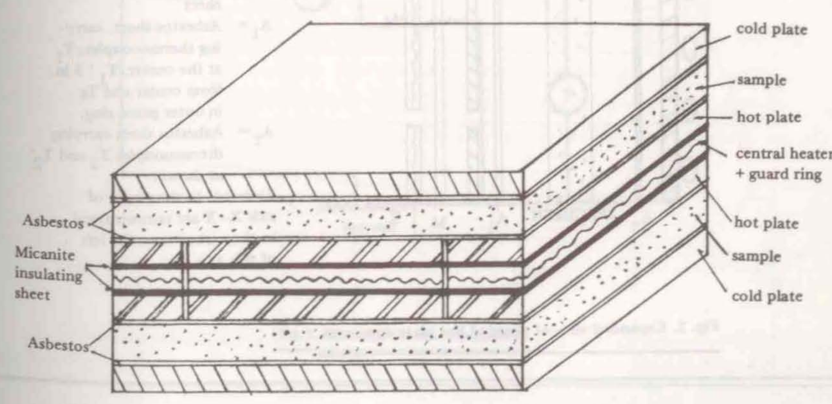


Fig. 1 General features of the guarded hot plate

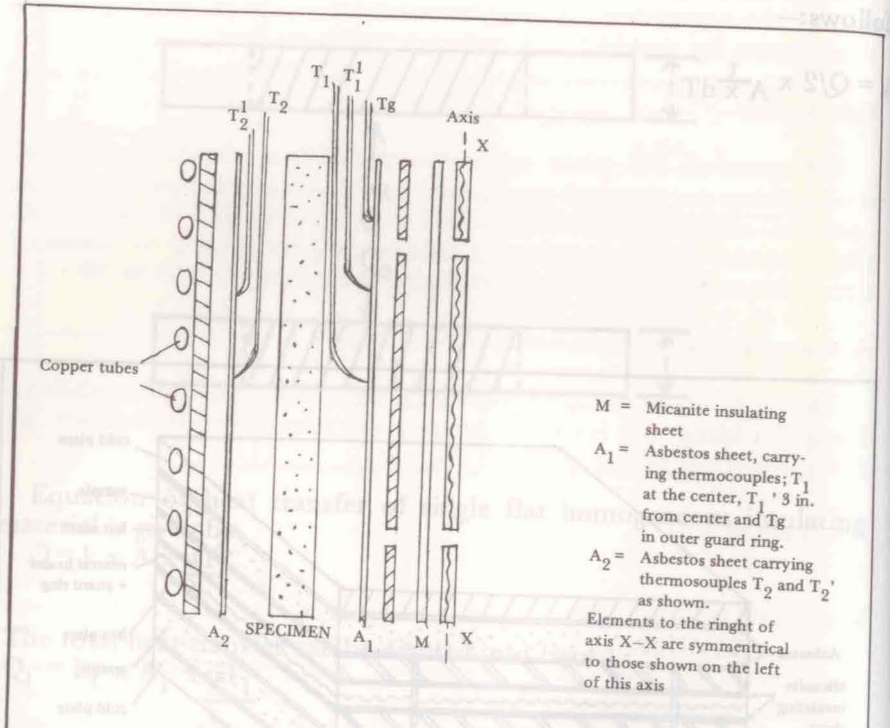


Fig. 2. Expanded view of guarded hot plate apparatus

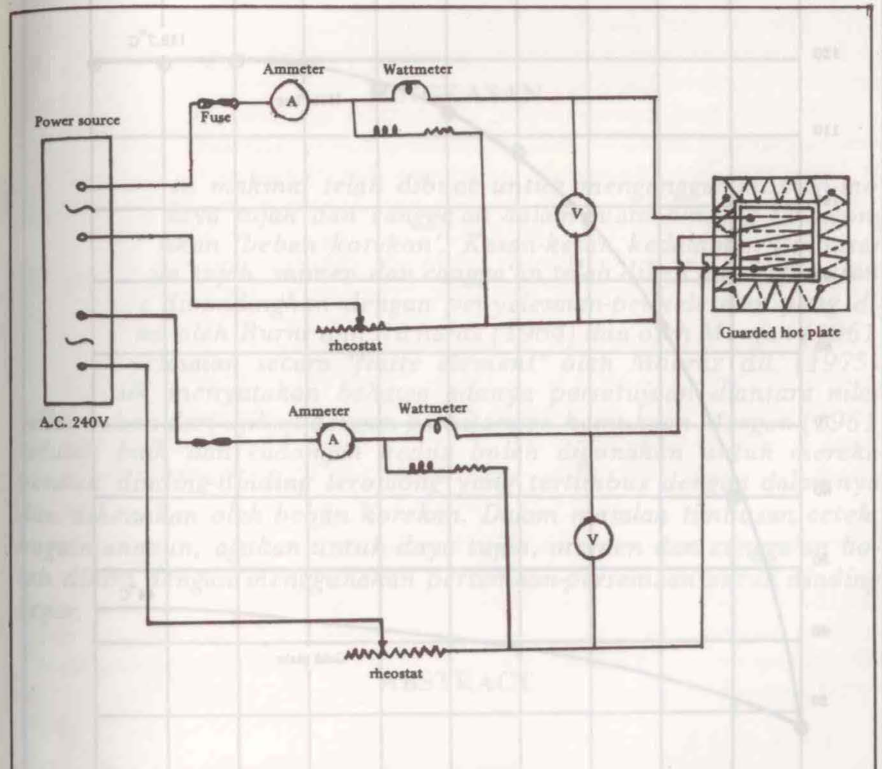


Fig. 3. Electrical Circuit Arrangement

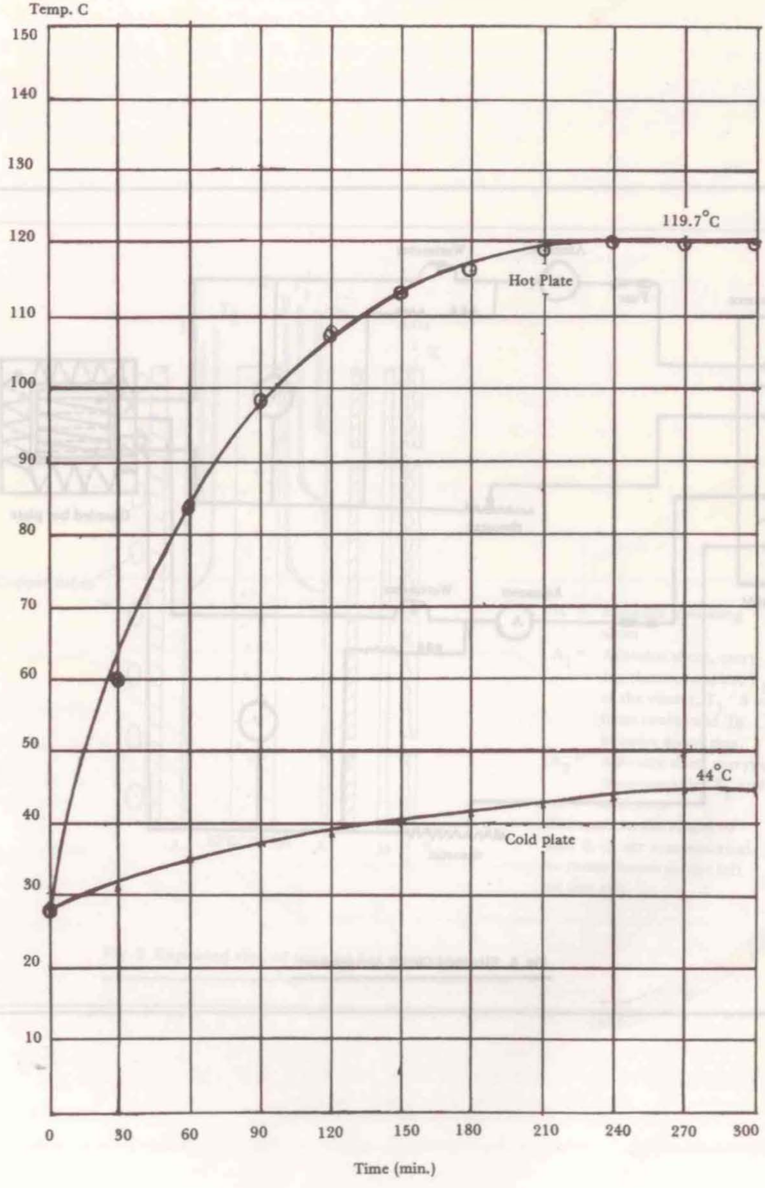


Fig. 4: Graph of temperature vs. time for polystyrene.