IS 9489 (1980): Method of test for thermal conductivity of materials by means of heat flow meter [CHD 27: Thermal Insulation]

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REAFFIRMED

Reaffirmed 1985

IS : 9489 - 1980

Indian Standard

METHOD OF TEST FOR THERMAL CONDUCTIVITY OF THERMAL INSULATION MATERIALS BY MEANS OF HEAT FLOW METER

UDC 662·998 : 536·21·083

INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 3 *November* 1980

Indian Standard

METHOD OF TEST FOR THERMAL CONDUCTIVITY OF THERMAL INSULATION MATERIALS BY MEANS OF HEAT FLOW METER

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AMENDMENT NO. 1 APRIL 1999
TO
IS 9489 : 1980 METHOD OF TEST FOR THERMAL CONDUCTIVITY OF THERMAL INSULATION MATERIALS BY MEANS OF HEAT FLOW METER

(*Page* 8, *clause* **3.8**) — Substitute the following for the existing text:

'A potentiometer or any other suitable equipment having a sensitivity of 0.1 percent of minimum output from the thermocouple or better and an accuracy of ±0.1 percent or better shall be used for measurement of all thermocouples and thermopile emf.'

(CHD 27)

Reprography Unit, BIS, New Delhi, India

Indian Standard

METHOD OF TEST FOR THERMAL CONDUCTIVITY OF THERMAL INSULATION MATERIALS BY MEANS OF HEAT FLOW METER

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 29 April 1980, after the draft finalized by the Thermal Insulation Materials Sectional Committee had been approved by the Chemical Division Council.

0.2 The heat flow meter method is generally used for routine determination of thermal conductivity of homogeneous materials in the form of flat slabs, but heat flow meters with modifications may also be used to measure heat flow through pipe insulation and built-up sections.

0.3 This method is capable of reproducing thermal conductivities within ±3 percent of those determined by IS : 3346-1980* with which the standard specimens have been calibrated. This is a secondary method for measuring the thermal conductivity of homogeneous insulating materials, since its calibration depends on the use of a pair of specimens whose thermal conductivity has been determined in accordance with IS : 3346-1980*, and therefore the method given in IS : 3346-1980* shall be used as a referee method wherever it is applicable.

0.4 Because of the requirements as to test conditions prescribed by this method, it shall be recognized that thermal conductivity obtained will not necessarily apply without modification to service conditions. As an example, this method provides that thermal conductivity shall be obtained on dry specimens although in service such conditions may not be realized.

0.5 It is not practical in a method of this type to try to establish details of construction and procedures to cover all contingencies that might offer difficulties to a person without technical knowledge concerning theory of heat flow, temperature measurements, and general testing practices. Standardization of this method is not intended to restrict in any way the future development of improved or new methods or procedures by research workers.

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*Method for the determination of thermal conductivity of thermal insulation materials (two slab, guarded hot-plate method) (*first revision*).

0.6 It shall be ensured that the portion of the specimen over the metering area is typical of the whole specimen in every aspect and that the remainder of the specimen does not, on average, distort the heat flow in the part of the specimen adjacent to the metering area, when this method is used. It shall also be ensured that the specimens are free of low thermal resistance paths that create thermal short circuits between the test surfaces and the heat flux through the specimens is directly proportional to the temperature difference across the specimens.

0.7 Considerable assistance has been taken from ASTM C 518-76 Method of test for thermal conductivity of materials by means of the heat flow meter. American Society for Testing and Materials, USA and is gratefully acknowledged.

0.8 In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

1. SCOPE

1.1 This standard prescribes the general procedure for the determination of thermal conductivity, by means of a heat flow meter, of homogeneous insulating materials whose thermal conductivities do not exceed the limits given in **1.1.1**.

1.1.1 For practical purposes this method is limited to the determination of thermal conductivity of specimens having conductivity not in excess of 0·29 W/mK.

1.1.2 For this method, the suggested limiting temperatures of the surfaces to be in contact with the heat flow meter are 225 K and 825 K. These limits may be extended in both directions, but shall be governed both by the materials of construction and by the calibration procedures.

2. TERMINOLOGY

2.1 For the purpose of this standard, the definitions of terms, symbols and units given in IS : 3069-1965† shall apply.

*Rules for rounding off numerical values (*revised*).

†Glossary of terms, symbols and units relating to thermal insulation materials.

3. APPARATUS

3.1 General — The general features of a heat flow meter apparatus with specimens installed are shown in Fig. 1. It shall consists of a hot (or cold) plate, a specimen, a heat flow meter, another specimen (optional), and a cold (or hot) plate in order. Surface temperature of hot plate, cold plate and heat flow meter shall be measured. The direction of heat flow and the use of two specimens is optional; if only one specimen is used it is necessary to measure the surface temperature of the heat flow meter only on the side contacting the specimen. A thin layer of material may be used to reduce temperature fluctuations in the one sample configuration. When a single specimen is utilized the apparatus may be termed as ' single specimen configuration '. The specimens may be placed against either plate. In the two-specimen configuration, the meter is placed between two substantially identical specimens cut from the same sample of material. Each configuration gives equivalent results if used within the limitations stated. The working surfaces of the plate and the heat flow meter shall be painted or otherwise treated to have a total emittance greater than 0·8 at operating temperatures.

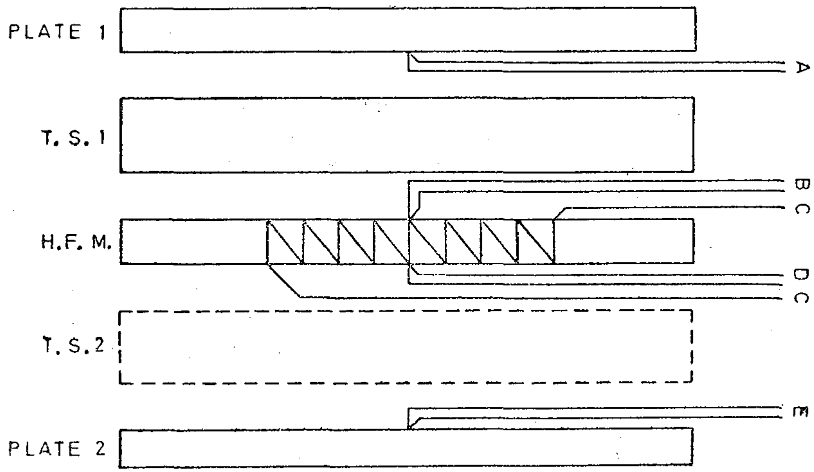

Plate 1 — Controlled temperature plate at T_1 (or T_2)
T.S. 1 — Test specimen 1
H.F.M. — Heat flow meter (simplified)
T.S. 2 — Test specimen 2 or damping layer
Plate 2 — Controlled temperature plate at T_2 (or T_1)
A and E — Plate surface thermocouples or transducers
B and D — Heat meter surface thermocouples
C — Heat meter thermopile or temperature-difference detector

FIG. 1 HEAT FLOW METER APPARATUS

3.2 Hot Plate — The hot plate shall be so constructed that an isothermal surface is obtained. This may be achieved by placing an electrical winding of uniform watt density between two metal plates, or by circulating a constant-temperature liquid between the plates, or by some other appropriate means. The working surface of the hot plate shall consist of a metal of high thermal conductivity and shall be smoothly finished to conform to a true plane to within 0·25 mm/m. The planeness of the surface may be checked with a steel straightedge, of a length greater than the width or diameter of the unit, held against the surface and viewed with a light behind the straightedge. Departures as small as 0·025 mm are readily visible, and larger departures may be measured using thin paper or other suitable means. Grooves shall be machined into the surface of the hot plate, to allow a thermocouple to be imbedded in the cement, flush with the surface, to measure the plate surface temperature.

3.3 Cold Plate — The cold plate shall be so constructed that an isothermal surface is obtained with a surface dimension at least as large as that of the hot plate. It shall consist of a metal plate of high thermal conductivity maintained at a temperature lower than that of the hot plate. A plate containing a constant-temperature liquid, an electrical heater, or a solid metal plate in contact with the specimen with thermal insulation of uniform conductance applied to the outermost surface, may be used as appropriate for the temperature desired. The working surface shall be smoothly finished to conform to a true plane to within 0·25 mm/m. Grooves shall be machined into the surface of the cold plate to allow a thermocouple to be imbedded in cement, flush with the surface, to measure the plate surface temperature.

3.4 Heat Flow Meter

3.4.1 *General*— The heat flow meter shall be constructed to have a sensitivity so that its output is equal to or greater than 0·2 mV for any test condition. It shall have an over-all face area equal to that of the hot plate.

3.4.2 *Core* — The core shall be constructed from a suitable thermal resistance material which shall be homogeneous, isotropic and nonhygroscopic and shall have parallel faces to assure a uniform heat flow normal to the faces. The core material shall not effectively change under the temperature and humidity conditions of use and storage. It shall be thermally uniform and shall remain stable over a long period of time. It shall be hard with low or no compressibility and should be easily fabricated. Some of the materials that may be used for heat flow meters are cork composition, hard rubber, plastics, ceramics, asbestos composition, etc.

3.4.3 *Thermopile* — A multijunction thermopile shall be placed on the surfaces of the core material of the heat flow meter to measure the heat flow. To assure that the heat flow is substantially perpendicular to the faces of the meter, the thermopile junctions shall either be uniformly distributed within the most central area of meter and this area shall be not larger than 40 percent nor less than 10 percent of the entire surface area, or shall be concentrated in areas of not less than 10 percent of the entire surface area and these areas shall be within the most central 40 percent of the meter. It is recommended that the thermopile be made of wire not larger than 0·26 mm in diameter (No. 33 SWG).

3.4.4 *Surface Sheets* — To prevent damage to the thermopile which will affect its calibration, both surfaces shall be covered with a layer of suitable material as thin as possible, similar to the core, by appropriate chemical or mechanical means. The working surfaces of the heat flow meter shall be smoothly finished to conform to a true plane to within 0·25 mm/m.

3.4.5 *Surface Temperature* — A suitable device shall be employed for measuring the average temperature of the sample side of the heat flow meter.

NOTE — A 0·08 mm thick piece of copper foil, adhered to the surface sheet, should be used to average the surface temperature of the heat flow meter over the areas where the junctions of the thermopile are placed. The foil should extend beyond this area by a distance approximately equal to the thickness of the heat flow meter. To eliminate the lump of solder that may be formed when attaching the thermocouple to the copper foil, a 0·26 mm diameter wire thermocouple is soldered to the back side of the foil and all of the excess solder is removed. The negative lead of the thermocouple is soldered to the centre of the foil while the positive lead is soldered near one of the edges. The two leads are strung through the surface sheet before the surface sheet is attached to the core. At the solder joints, small amounts of the surface sheet may be sanded away to eliminate any lumps. The surface of the meter not covered by the metal foil is masked by an applied sheet of non metal 0·0 8 mm in thickness to assure a true plane.

3.5 Framework — A framework shall be provided to hold the apparatus in any one or more orientations. Means shall be provided to apply a reproducible constant pressure, about 2·5 kPa, to the assembly to assure a good surface contact with the specimen. If the specimen is not able to resist this force without compressing, small stops shall be placed between the corners of the hot and cold plates or some other positive means shall be used to limit the compression of the specimens.

3.6 Edge-Insulation — Heat losses from the outer edges of the heat flow meter apparatus and specimens shall be restricted by edge insulation, or by governing the surrounding air temperature, or by both methods. It is recommended that the total of such heat losses should not exceed 20 percent of the heat-flow through the specimen.

NOTE — A cabinet or enclosure surrounding the heat flow meter assembly to maintain the ambient temperature at the mean temperature of the specimen and means to maintain the dew point temperature at least 5 K lower than the temperature of the cold plates to prevent condensation and moisture pick-up by the specimen, are recommended while conducting tests at mean temperature differing substantially from the laboratory air temperature.

3.7 Thermocouples — The thermocouples that are used to measure the temperature of the hot and cold faces of the specimen shall be fabricated from calibrated thermocuple wire not larger than 0·29 mm in diameter (No. 32 SWG) and preferably of 0·19 mm diameter (No. 36 SWG).

3.8 Potentiometer — A potentiometer system having a sensitivity of 0·1 percent of minimum output from the thermocouples or better and an accuracy of $\pm$ 0·1 percent or better shall be used for measurements of all thermocouples and thermopile emf.

3.9 Thickness Measuring Device — Means shall be provided for measuring the thickness of the specimen to 0·025 mm at each test temperature, either with the specimen in the apparatus or removed.

4. SAMPLING AND PREPARATION OF SPECIMENS

4.1 Conduct the sampling and preparation of the specimens in accordance with **5** of IS : 3346-1980* with the exception that a single specimen may be used for test.

4.2 The relationship between the combined thickness of the heat flow meter and the specimen or specimens and the dimensions of the heat flow meter shall be as follows:

Combined Max Thickness of Specimen or Specimens and Heat Flow Meter	*Min Linear Dimensions of Heat Flow Meter*
mm	mm
35	200
50	300
65	450
100	650

5. CALIBRATION

5.1 Calibrate the heat flow meter by the comparative method with the

*Method for the determination of thermal conductivity of thermal insulation materials (two slab, guarded hot-plate method) (*first revision*).

use of a pair of thermally matched rigid specimens whose average thermal conductivity has been determined in accordance with IS : 3346-1980*. Although the conductivity of each specimen (λ_1 and λ_2) is unknown, the average conductivity (λavg) is:

$$\lambda_{avg} = \frac{\lambda_1 + \lambda_2}{2}$$

NOTE — The heat flow meter may also be calibrated according to IS : 3346-1980* with modifications to suit the following conditions:

a) The guarded hot plate should be one side, and
b) The metering area of the guarded hot plate should be equal to or larger than the metering area of the heat flow meter.

5.2 The calibration requires two tests, each made in the heat flow meter apparatus as given in **6**. Each of the two tests employs the heat flow meter and one of the two standard specimens. Care shall be exercised that the mean temperature of the specimens and the ambient temperature of the air are the same in both tests.

Calculate the sensitivity of the heat flow meter as follows:

$$S = \lambda_{avg} \left[\frac{(\Delta T_1/D_1 e_1) + (\Delta T_2/D_2 e_2)}{2} \right]$$

where

S = sensitivity of heat flow meter in W/m²V;
λ_{avg} = average thermal conductivity of the two standard specimens, W/mK;
ΔT_1 and ΔT_2 = temperature difference across the standard specimens No. 1 and No. 2 respectively, K;
D_1 and D_2 = thickness of standard specimen No. 1 and No. 2 respectively, m, and
e_1 and e_2 = output of the heat flow meter when using standard specimens No. 1 and No. 2, respectively, V.

5.3 As most heat flow meters are temperature sensitive and change with the mean temperature, the above measurements shall be repeated at different mean temperatures to cover the temperature range of use of the heat flow meter. Prepare a calibration curve (sensitivity versus mean temperature).

5.4 Check the heat flow meter for calibration at least once every month and maintain a running record of calibration results. If the checks indicate a difference in the thermal conductivity of the standard specimens of more than 1 percent then a new calibration curve shall be prepared.

*Method for the determination of thermal conductivity of thermal insulation materials (two slab, guarded hot-plate method) (*first revision*).

6. PROCEDURE FOR SINGLE SPECIMEN CONFIGURATION

6.1 For any test make the temperature difference across the specimen not less than 5 K. It is recommended that for good insulators the temperature gradient of the specimen be 900 K/m or more.

6.2 Place the conditioned specimen into the apparatus between the heat flow meter and the cold plate.

NOTE — The specimen may be placed between the hot plate and the heat flow meter if it is desired to determine thermal conductivities at higher temperatures than the safe temperature limit of the heat flow meter.

6.3 Wrap the edges of the heat flow meter assembly with the required thermal insulation to minimize edge heat losses (*see* **3.6**).

6.4 Control the cold plate so that the temperature during the test period does not fluctuate or change in 1 h by more than 0·5 percent of the temperature difference between the hot and cold plates.

6.5 Control the hot plate so that the temperature during the test period does not fluctuate or change 1 in h by more than 0·5 percent of the temperature difference between the hot and cold plates.

6.6 To establish thermal equilibrium, continue the test, observing the mean temperature and the emf output of the heat flow meter, and the mean temperature and the temperature drop across the specimen. Make observations every 5 min until five successive observations yield a thermal conductivity value agreeing to within 1 percent.

6.7 Upon completion of the test reweigh the specimen and measure the thickness.

7. CALCULATIONS

7.1 Calculate the density of the specimen.

7.2 Calculate the thermal conductivity as follows:

$$\lambda = Se\ (D/\Delta T)$$

where

λ = thermal conductivity of the specimen, W/mK;
S = sensitivity of the heat flow meter, W/m^{2}V;
e = heat flow meter output, V;
D = thickness of specimen, m; and
ΔT = temperature difference across the specimen, K.

8. REPORT

8.1 The report of the results of each test shall include the following:

a) Name and any other pertinent identification of the materials.

b) Thickness of specimen as tested.

c) Method and temperature used in drying specimen.

d) Density of dry specimen as tested.

e) Moisture content of specimen as received, as percent of dry mass.

f) Moisture regain of specimen during test, as percent of dry mass or volume or both.

g) Temperature gradient of the specimen during test.

h) Mean temperature of the test.

j) Heat flux through the specimen.

k) Thermal conductivity, or thermal conductance, of the specimen.

m) Orientation of heat meter apparatus during test (vertical, horizontal, etc).

INDIAN STANDARDS

ON

THERMAL INSULATION MATERIALS

IS:

661-1964	Code of pratice for thermal insulation of cold storages (*second revision*)
3069-1965	Glossary of terms, symbols and units relating to thermal insulation materials
3144-1965	Methods of test for mineral wool thermal insulation materials
3346-1980	Methods for the determination of thermal conductivity of thermal insulation materials (two-slab, guarded hot-plate method) (*first revision*)
3677-1973	Unbonded rock and slag wool for thermal insulation (*first revision*)
3690-1974	Unbonded glass wool for thermal insulation (*first revision*)
4671-1968	Expanded polystyrene for thermal insulation purposes
5688-1970	Methods of test for preformed block-type and pipe covering type thermal insulation
5724-1970	Methods of test for thermal insulating cements
6598-1972	Cellular concrete for thermal insulation
7240-1974	Code of practice for application and finishing of thermal insulation materials between — 80°C and 40°C
7413-1974	Code of practice for the application and finishing of thermal insulation materials between 40°C and 700°C
7509-1974	Thermal insulating cements (type 750)
7510-1974	Thermal insulating cements (type 350)
8154-1976	Preformed calcium silicate insulation (for temperature up to 650°C)
8183-1976	Bonded mineral wool
9350-1980	Thermal insulating cement (type 950)
9428-1980	Preformed calcium silicate insulation (for temperature up to 950°C)

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

Quantity	*Unit*	*mbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Unit*	*Symbol*	*Definition*
Force	newton	N	1 N = 1 kg. m/s²
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m²
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m²

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Printed at Neelkamal Printers, Delhi, India