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Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus

Isolation thermique — Détermination de la résistance thermique et des propriétés connexes en régime stationnaire — Méthode fluxmétrique

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Contents

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Annexes

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 8301 was prepared by Technical Committee ISO/TC 163, *Thermal insulation*.

Annex A forms an integral part of this International Standard. Annexes B, C, D and E are for information only.

Introduction

0.1 Document subdivision

This International Standard is divided into three sections representing the most comprehensive assembly of information required to use the heat flow meter apparatus:

Section 1: General considerations

Section 2: Apparatus and calibration

Section 3: Test procedures

While the user of the method may need to concentrate only on section 3 for test purposes, he must also be familiar with the other two in order to obtain accurate and precise results. He must be particularly knowledgeable about the general requirements. Section 2 is directed towards the constructor of the apparatus, but he also, in order to build good apparatus, must be familiar with the other sections.

0.2 Heat transfer and measured properties

A large number of tests are run on light-density porous materials. In such cases the actual heat transfer within them can involve a complex combination of different contributions of

— radiation;

— conduction both in the solid and in the gas phase;

— convection (in some operating conditions);

plus their interaction, together with mass transfer, especially in moist materials. Therefore, the heat transfer property, very often improperly called "thermal conductivity", calculated from a defined formula and the results of measurements of heat transfer rate, temperature difference and dimensions for a specimen may be not an intrinsic property of the material itself. This property, in accordance with ISO 9288, should therefore be called the "transfer factor" as it may depend on the test conditions (the transfer factor is often referred to elsewhere as apparent or effective thermal conductivity). The transfer factor may have a significant dependence on the thickness of the specimen and/or on the temperature difference for the same mean test temperature.

Heat transfer by radiation is the first source of dependence of the transfer factor on specimen thickness. As a consequence, not only the material properties but also the radiative characteristics of the surfaces bounding the specimen influence results. Thermal resistance is therefore the property that better describes the thermal behaviour of the specimen, provided that it is accompanied by information on the bounding surfaces.

If there is any possibility of the onset of convection within the specimen (e.g. in light mineral wool for low temperatures), the apparatus orientation, the thickness and the temperature difference can influence both the transfer factor and the thermal resistance. In such cases, as a minimum it is required that the geometry and the boundary conditions of the specimen tested be fully specified, even though information supplied in the test procedures does not cover these test conditions in detail. In addition, it will take considerable knowledge to evaluate the measurement as such, especially when applying the measured values in practice.

The influence of moisture within a specimen on the heat transfer during a measurement is also a very complex matter. Dried specimens only therefore ought to be tested according to standard procedures. Measurements on moist materials need additional precautions not covered in detail in this International Standard.

The knowledge of the physical principles is also extremely important when a heat transfer property, determined by this test method, is used to predict the thermal behaviour of a specific material in a practical application even though other factors such as workmanship can influence this behaviour.

0.3 Background required

The design and subsequent correct operation of a heat flow meter (HFM) apparatus (see 1.6.1 and 2.2.2) to obtain correct results and the interpretation of experimental results is a complex subject requiring great care. It is recommended that the designer, operator and user of measured data of the HFM apparatus should have a thorough background of knowledge of heat transfer mechanisms in the materials, products and systems being evaluated, coupled with experience of electrical and temperature measurements particularly at low signal levels. Good laboratory practice in accordance with general test procedures should also be maintained.

The in-depth knowledge in each area cited may be different for the designer, operator, and data user.

0.4 Design, size, and national standards

Many different designs of heat flow meter apparatus exist worldwide to conform to present national standards. Continuing research and development is in progress to improve the apparatus and measurement techniques. Thus it is not practical to mandate a specific design or size of apparatus especially as total requirements may vary quite widely.

0.5 Guidelines supplied

Considerable latitude both in the temperature range and in the geometry of the apparatus is given to the designer of new equipment since various forms have been found to give comparable results. It is recommended that designers of new apparatus carefully read the comprehensive literature cited in annex E. After completion of new apparatus it is recommended that it should be checked by undertaking tests on one or more of the various reference materials of different thermal resistance levels now available. This International Standard outlines only the mandatory requirements necessary to design and operate heat flow meter apparatus in order to provide correct results. A table summarizing limit values for the apparatus performance and testing conditions stated in this International Standard is supplied in annex A. It also includes recommended procedures and practices plus suggested specimen dimensions which together should enhance general measurement levels and assist in improving inter-laboratory comparison and collaborative measurement programmes.

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Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus

Section 1: General

1.1 Scope

1.1.1 This International Standard defines the use of the heat flow meter method (see 2.2.2) to measure the steady-state heat transfer through flat slab specimens and the calculation of the heat transfer properties of specimens.

This is a secondary or relative method since the ratio of the thermal resistance of the specimen(s) to that of a standard specimen(s) is measured.

Reports conforming to this standard test method shall refer to specimens with thermal resistance greater than 0,1 m²·K/W provided that thickness limits given in 1.7.2 are not exceeded.

1.1.2 If the specimens satisfy the requirements outlined in 1.8.1, the resultant properties shall be described as the thermal conductance and thermal resistance of the specimen.

1.1.3 If the specimens satisfy the requirements of 1.8.2, the resultant properties shall be described as the mean thermal conductivity of the specimen being evaluated.

1.1.4 If the specimens satisfy the requirements of 1.8.3, the resultant property may be described as the thermal conductivity or the transmissivity of the material being evaluated.

1.2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 7345:1987, *Thermal insulation — Physical quantities and definitions.*

ISO 8302:1991, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus.*

ISO 9229:—[1], *Thermal insulation — Materials, products and systems — Vocabulary.*

ISO 9251:1987, *Thermal insulation — Heat transfer conditions and properties of materials — Vocabulary.*

ISO 9288:1989, *Thermal insulation — Heat transfer by radiation — Physical quantities and definitions.*

ISO 9346:1987, *Thermal insulation — Mass transfer — Physical quantities and definitions.*

1.3 Definitions

For the purposes of this International Standard, the following definitions apply.

The following quantities are defined in ISO 7345 or ISO 9251:

1) To be published.

Quantity	Symbol	Units
Heat flow-rate	Φ	W
Density of heat flow-rate	q	W/m^2
Thermal resistance[1)]	R	$m^2 \cdot K/W$
Thermal conductance	Λ	$W/(m^2 \cdot K)$
Thermal conductivity[2)]	λ	$W/(m \cdot K)$
Thermal resistivity	r	$m \cdot K/W$
Porosity	ξ	
Local porosity	ξ_p	

1) In some cases it may be necessary to consider also the temperature difference divided by the heat flow rate; no special symbol is assigned to this quantity, sometimes also called resistance.

2) In the most general case $\vec{q}$ and grad T do not have the same orientation ($\overset{\rightrightarrows}{\lambda}$ is not defined through a single constant λ but through a matrix of constants); moreover conductivity changes while changing position within the body, while changing the temperature and changes with time.

The following definitions related to material properties are given in ISO 9251:

- porous medium
- homogeneous medium
- homogeneous porous medium
- heterogeneous medium
- isotropic medium
- anisotropic medium
- stable medium

Other terms not defined in ISO 7345 or ISO 9251:

1.3.1 thermally homogeneous medium: Is one in which thermal conductivity $[\overset{\rightrightarrows}{\lambda}]$ is not a function of the position within the medium but may be a function of direction, time and temperature.

1.3.2 thermally isotropic medium: Is one in which thermal conductivity $[\overset{\rightrightarrows}{\lambda}]$ is not a function of direction but may be a function of the position with the medium, of time and of the temperature ($[\overset{\rightrightarrows}{\lambda}]$ is defined through a single value λ in each point).

1.3.3 thermally stable medium: Is one in which thermal conductivity λ or $[\overset{\rightrightarrows}{\lambda}]$ is not a function of time, but may be a function of the co-ordinates, of the temperature and, when applicable, of the direction.

1.3.4 mean thermal conductivity of a specimen: Is the property defined in steady-state conditions in a body that has the form of a slab bounded by two parallel, flat isothermal faces and by adiabatic edges perpendicular to the faces, that is made of a material thermally homogeneous, isotropic (or anisotropic with a symmetry axis perpendicular to the faces), stable only within the precision of a measurement and the time required to execute it, and with thermal conductivity λ or $[\overset{\rightrightarrows}{\lambda}]$ constant or a linear function of temperature.

1.3.5 transfer factor of a specimen: Is defined by

$$\mathcal{T} = \frac{qd}{\Delta T} = \frac{d}{R} \; W(m \cdot K)$$

It depends on experimental conditions and characterizes a **specimen** in relation with the combined conduction and radiation heat transfer. It is often referred to elsewhere as measured, equivalent, apparent or effective thermal conductivity of a **specimen**.

1.3.6 thermal transmissivity of a material: It is defined by

$$\lambda_t = \frac{\Delta d}{\Delta R} \; W/(m \cdot K)$$

when $\Delta d/\Delta R$ is independent of the thickness d. It is independent of experimental conditions and characterizes an insulating **material** in relation with combined conduction and radiation. Thermal transmissivity can be seen as the limit reached by the transfer factor in thick layers where combined conduction and radiation heat transfer takes place. It is often referred to elsewhere as equivalent, apparent or effective thermal conductivity of a **material**.

1.3.7 steady-state heat transfer property: Generic term to identify one of the following properties: thermal resistance, transfer factor, thermal conductivity, thermal resistivity, thermal transmissivity, thermal conductance, mean thermal conductivity.

1.3.8 room temperature: Generic term to identify a mean test temperature of a measurement such that a man in a room would regard it comfortable if it were the temperature of that room.

1.3.9 ambient temperature: Generic term to identify the temperature in the vicinity of the edge of the specimen or in the vicinity of the whole apparatus. This temperature is the temperature within the cabinet where the apparatus is enclosed or that of the laboratory for non-enclosed apparatus.

1.3.10 operator: Person responsible for carrying out the test on a heat flow meter apparatus and for the presentation through a report of measured results.

1.3.11 data user: Person involved in the application and interpretation of measured results to judge material or system performance.

1.3.12 designer: Person who develops the constructional details of an apparatus in order to meet predefined performance limits for the apparatus in assigned test conditions and who identifies test procedures to verify the predicted apparatus accuracy.

1.4 Symbols and units

Symbol	Quantity	Units
A	Area measured on a selected isothermal surface, or metering area	m^2
c_s	Specific heat capacity	J/(kg·K)
d	Thickness of specimen measured along a path normal to isothermal surfaces	m
d, d''	Thickness for each specimen in a two-specimen configuration HFM apparatus	m
d_m	Mean thickness of a pair of two specimens	m
$d_1, d_2, ..., d_5$	Thickness of specimens designated $s_1, s_2, ..., s_5$	m
D_t	Maximum allowable distance between hot and cold plates during the test	m
e	Heat flow meter output	mV
f	Calibration factor of the heat flow meter	W/(mV·m^2)
L	Length of the side of heat flow meter(s)	m
L_m	Length of the side of heat flow meter metering area	m
m_c	Relative mass change after conditioning	—
m_d	Relative mass change due to conditioning after drying	—
m_r	Relative mass change after drying	—
m_w	Relative mass change of a specimen during the test	—
M_1	Mass in as-received condition	kg
M_2	Mass after drying	kg
M_3	Mass after conditioning	kg
M_4	Mass after test	kg
M_5	Mass of dried or conditioned material, immediately before test	kg
q	Density of heat flow-rate	W/m^2
q', q''	Density of heat flow-rate for each specimen in a two-specimen configuration HFM apparatus	W/m^2
r	Thermal resistivity	m·K/W
r_{avg}	Average thermal resistivity in a two-specimen configuration HFM apparatus	m·K/W
R	Thermal resistance	m^2·K/W
R_s	Thermal resistance of the standard specimen	m^2·K/W
R_u	Thermal resistance of the unknown specimen	m^2·K/W
R_t	Total thermal resistance in a two-specimen configuration HFM apparatus	m^2·K/W
$s_1, s_2, ..., s_5$	Set of specimens of different thicknesses	—
$\mathcal{T}$	Transfer factor of a specimen	W/(m·K)
$T_m = (T_1 + T_2)/2$	Mean temperature	K
T'_1, T''_1	Hot side temperatures for each specimen in a two-specimen configuration HFM apparatus	K
T'_2, T''_2	Cold side temperature for each specimen in a two-specimen configuration HFM apparatus	K
T'_m	Mean temperature of specimen (′) in a two-specimen configuration HFM apparatus	K
T''_m	Mean temperature of specimen (″) in a two-specimen configuration HFM apparatus	K

Symbol	Quantity	Units
V	Volume	m^3
Δd	Increment of thickness	m
$\delta d = (d' - d'')/2$	Mean thickness difference of specimens (′) and (″) in a two-specimen configuration HFM apparatus	m
$\delta\lambda$	Deviation of thermal conductivity at mean temperature T_m of specimens (′) and (″)	W/(m·K)
$\delta T_m = (T'_m - T''_m)/2$	Mean deviation between the mean temperature of specimen (′) and (″)	K
$\delta T = (\Delta T' - \Delta T'')/2$	Mean deviation between the temperature differences of specimens (′) and (″)	K
ΔR	Increment of thermal resistance	m^2·K/W
$\Delta T = T_1 - T_2$	Temperature difference	K
$\Delta T'$, $\Delta T''$	Temperature differences for each specimen (′) and (″) in a two-specimen configuration HFM apparatus	K
$\frac{\Delta e}{\Delta q}$	Sensitivity coefficient of the HFM	mV/(W·m^2)
Φ	Heat flow-rate	W
Φ_u	Heat flow-rate with unknown specimen	W
Φ_s	Heat flow rate with "standard" or "reference" specimen	W
λ	Thermal conductivity	W/(m·K)
λ', λ''	Thermal conductivity for each specimen (′) and (″) in a two-specimen configuration HFM apparatus	W/(m·K)
$\dot{\lambda}(T)$	First order temperature derivative of λ (T)	W/(m·K^2)
$\ddot{\lambda}(T)$	Second order temperature derivative of λ (T)	W/(m·K^3)
λ_{avg}	Average thermal conductivity in a two-specimen configuration HFM apparatus	W/(m·K)
λ_m	Mean thermal conductivity of a specimen or thermal conductivity at the mean temperature T_m	W/(m·K)
λ_M	Mean thermal conductivity of specimens (′) and (″) measured in a guarded hot plate apparatus	W/(m·K)
λ_t	Thermal transmissivity of a material	W/(m·K)
Λ	Thermal conductance	W/(m^2·K)
ρ_d	Density of the dry material as tested	kg/m^3
ρ_s	Density of the material after conditioning	kg/m^3
$\rho \cdot c_s$	Product of as-tested density and specific heat of the specimen	J/(m^3·K)
ξ	Porosity	—
ξ_p	Local porosity	—
(′), (″)	Indexes used to refer to properties of the first and the second specimen in a two-specimen configuration HFM apparatus	—

1.5 Significance

1.5.1 Factors influencing thermal properties

The thermal transmission properties of a specimen of material may

- vary due to variability of the composition of the materials or samples of it;
- be affected by moisture or other factors;
- change with time;
- change with mean temperature;
- depend upon the prior thermal history.

It must be recognized, therefore, that the selection of a typical value of heat transfer properties representative of a material, in a particular application, shall be based on a consideration of these factors and will not necessarily apply without modification to all service conditions.

As an example this method provides that the heat transfer properties shall be obtained on dried specimens, although in service such conditions may not be realized. Even more basic is the dependence of the heat transfer properties on variables such as mean temperature and temperature difference. Such dependence should be measured or the test made under conditions typical of use.

1.5.2 Sampling

Heat transfer properties need adequate information to be considered representative of a material. A heat transfer property of a material can be determined by a single measurement only if the sample is typical of the material and the specimen(s) is (are) typical of the sample.

The procedure for selecting the sample should normally be specified in the material specification. The selection of the specimen from the sample may be partly specified in the material specification.

As sampling is beyond the scope of this method, when the problem is not covered by a material specification, reference shall be made to appropriate documents.

1.5.3 Accuracy and reproducibility

Evaluation of the accuracy of the method is complex and is a function of the apparatus design, of the related instrumentation and of the type of specimens under test. The accuracy and the calibration should be a function of the reference material.

1.5.3.1 The reproducibility of subsequent measurements made by the apparatus on a specimen maintained within the apparatus without change in test conditions is normally much better than 1 %. When measurements are made on the same reference specimen removed and then mounted again after long time intervals, the reproducibility of measurements is normally better than $\pm$ 1 %. This larger figure is due to minor changes in test conditions such as the pressure of the plates and heat flow meter on the specimen (that affects contact resistances), and the relative humidity of the air around the specimen (that affects its moisture content). These levels of reproducibility are required to identify errors in the method and are desirable in quality control application.

1.5.3.2 The accuracy of the calibration of heat flow meter apparatus is normally within $\pm$ 2 % when the mean temperature of the test is near the room temperature.

The accuracy of calibration is mainly due to the accuracy of the guarded hot plate method when measuring the properties of reference specimens.

1.5.3.3 As a consequence this method is capable of determining the heat transfer properties within $\pm$ 3 % when the mean temperature of the test is near the room temperature.

1.5.4 Calibration procedure

One of the following procedures shall be followed.

1.5.4.1 The test-laboratory apparatus shall be calibrated (see 2.4) within 24 h before or after the test using calibration standards that have been issued by a recognized standard laboratory. Stability of calibration standards depends upon the type of material; some calibration standards have been successfully used over 20 years but it is suggested to check them at least each 5 years. The reported test and the apparatus calibration test shall be carried out using approximately the same hot- and cold-side temperatures as were used in the official calibration of the standards.

1.5.4.2 Where both short- and long-term stabilities of the heat flow meter have been proved to be better than $\pm$ 1 % of the reading, the heat flow meter apparatus may be calibrated at less frequent intervals, for example 15 d to 30 d. The specimens so tested cannot be reported until after the calibration following the test and then only if the change in calibration from the previous test is less than 1 %.

The average of the two calibrations shall be used as the calibration factor and the specimens tested with this value. When the change in calibration is greater than $\pm$ 1 %, test results from this interval