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Thermal insulation — Determination of steady-state thermal transmission properties of thermal insulation for circular pipes

Isolation thermique — Détermination des propriétés relatives au transfert de chaleur en régime stationnaire dans les isolants thermiques pour conduites

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Contents

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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 8497 was prepared by Technical Committee ISO/TC 163, *Thermal insulation*, Subcommittee SC 1, *Test and measurement methods*.

Annex A of this International Standard is for information only.

Introduction

The thermal transmission properties of pipe insulation generally have to be determined using pipe test apparatus rather than flat specimen apparatus such as the guarded hot plate or the heat flow meter apparatus, if results are to be representative of end-use performance. Insulation material formed into flat sheets often has different internal geometry from that of the same material formed into cylindrical shapes. Furthermore, properties often depend significantly upon the direction of heat flow in relation to inherent characteristics such as fibre planes or elongated cells: thus flat specimen one-dimensional heat flow measurements may not necessarily be representative of the two-dimensional radial heat flow encountered in pipe insulation.

Another consideration is that commercial insulations for pipes are often made with the inside diameter slightly larger than the outside diameter of the pipe, otherwise manufacturing tolerances may result in an imperfect fit on the pipe, thus creating an air gap of variable thickness. In those cases where end-use performance data rather than material properties are to be determined, the insulation is mounted on the test pipe in the same loose manner so that the effect of the air gap will be included in the measurements. This would not be the case if properties were determined in a flat plate apparatus where good plate contact is required.

Still another consideration is that natural convection currents around insulation installed on a pipe will cause non-uniform surface temperatures. Such conditions will not be duplicated in a flat plate apparatus with uniform plate temperatures.

NOTE 1 Comparison tests on apparently similar material using both pipe apparatus and flat plate apparatus have shown varying degrees of agreement of measured thermal transmission properties. It appears that better agreement is often obtained for heavier density products which tend to be more uniform, homogeneous and sometimes more isotropic. For those materials which have repeatedly shown acceptable agreement in such comparisons, the use of data from flat plate apparatus to characterize pipe insulation may be justified. As a general rule, when such agreement has not been shown, the pipe test apparatus shall be used to obtain thermal transmission data for pipe insulations.

Thermal insulation — Determination of steady-state thermal transmission properties of thermal insulation for circular pipes

1 Scope

This International Standard specifies a method for the determination of steady-state thermal transmission properties of thermal insulations for circular pipes generally operating at temperatures above ambient. It specifies apparatus performance requirements, but it does not specify apparatus design.

The type of specimen, temperatures and test conditions to which this International Standard applies are specified in clauses 5 and 6.

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 8301:1991, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus.*

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

3 Definitions

NOTE 2 The geometry of pipe insulation requires special terms not applicable to flat specimens. The word "linear" is used to denote properties based upon a unit length (in the pipe axis direction) of a specified insulation size. These linear properties, identified by the subscript "l", are convenient since the total heat loss can then be calculated knowing the pipe length and the applicable temperature.

"Linear" does not denote heat flow in the axial direction. In this International Standard, the direction of heat flow is predominantly radial.

For the purposes of this International Standard, the following definitions apply. The definitions and symbols given in the following clauses are based upon those in ISO 7345 except for the linear thermal transference (3.1).

3.1 linear thermal transference, K_l: Linear density of heat flow rate divided by the temperature difference between the pipe surface and the ambient air in the steady-state condition. It relates to a specific insulation size and is a measure of the heat transferred through the insulation to the ambient atmosphere.

$$K_l = \frac{\Phi/L}{T_0 - T_a} \qquad \ldots (1)$$

3.2 linear thermal resistance, R_l: Temperature difference between the pipe surface and the insulation outer surface divided by the linear density of heat flow rate in the steady-state condition. It relates to a specific insulation size and is the reciprocal of the pipe linear thermal conductance, Λ_l.

$$R_l = \frac{T_0 - T_2}{\Phi/L} = \frac{1}{\Lambda_l} \qquad \ldots (2)$$

3.3 linear thermal conductance, Λ_l: Reciprocal of the linear thermal resistance, R_l, from the pipe surface to the insulation outer surface. It relates to a specific insulation size.

$$\Lambda_l = \frac{1}{R_l} = \frac{\Phi/L}{T_0 - T_2} \qquad \ldots (3)$$

3.4 surface coefficient of heat transfer, h_2: Areal density of heat flow rate at the surface in the steady-state condition divided by the temperature difference between the surface and the surrounding ambient air. For pipe insulation geometry the following relation applies.

$$h_2 = \frac{\Phi}{\pi D_2 L(T_2 - T_a)} \qquad \ldots (4)$$

3.5 thermal conductivity, λ: Defined by the following relation specifically applicable to the pipe insulation geometry. It applies to homogeneous material in the steady-state condition and is the reciprocal of the thermal resistivity, r.

$$\lambda = \frac{\Phi \ln(D_2/D_0)}{2\pi L(T_0 - T_2)} = \frac{1}{r} \qquad \ldots (5)$$

NOTES

3 In ISO 7345, the thermal conductivity is also defined by the more general relation $q = -\lambda \operatorname{grad} T$.

4 Since the pipe surface temperature, T_0, is used, the thermal conductivity will include the effect of any gap that exists between the insulation and the pipe (see 6.1).

3.6 thermal resistivity, r: Reciprocal of the thermal conductivity, λ, for a homogeneous material in the steady-state condition.

$$r = \frac{2\pi L(T_0 - T_2)}{\Phi \ln(D_2/D_0)} = \frac{1}{\lambda} \qquad \ldots (6)$$

3.7 areal thermal resistance, R: Temperature difference between the pipe surface and the insulation outer surface divided by the areal density of heat flow rate in the steady-state condition. It is the reciprocal of the areal thermal conductance, Λ.

$$R = \frac{T_0 - T_2}{\Phi/A} = \frac{1}{\Lambda} \qquad \ldots (7)$$

where the surface of area A must be specified (usually the pipe surface, sometimes the insulation outer surface, or other as chosen; see note 6 in 3.8).

NOTE 5 The more common "areal" properties, based upon unit area, are often confusing when applied to pipe insulation since the area must be chosen arbitrarily and may range from that of the pipe surface to that of the insulation outer surface. If these areal properties are computed, the area and its location used in the computation must be reported.

3.8 areal thermal conductance, Λ: Reciprocal of the areal thermal resistance, R.

$$\Lambda = \frac{1}{R} = \frac{\Phi/A}{T_0 - T_2} \qquad \ldots (8)$$

where the location of the surface of area A must be specified (usually the pipe surface, sometimes the insulation outer surface, or other as chosen).

NOTE 6 The value of Λ, the areal thermal conductance, is arbitrary since it depends upon an arbitrary choice of the area, A. For a homogeneous material for which the thermal conductivity is defined as in 3.5, the areal conductance, Λ, is given by

$$\Lambda = \frac{2\pi L \lambda}{A \ln(D_2/D_0)} \qquad \ldots (9)$$

If the area is specially chosen to be the "log mean area", equal to $\pi L(D_2 - D_0)/\ln(D_2/D_0)$ then $\Lambda = 2\lambda/(D_2 - D_0)$. Since $(D_2 - D_0)/2$ is equal to the insulation thickness measured from the pipe surface, this is analogous to the relation between conductance and conductivity for flat slab geometry. Similar relations exist for the areal thermal resistance, R, defined in 3.7. Since these areal coefficients are arbitrary and since the area used is often not stated, thus leading to possible confusion, it is recommended that they be used only if specified.

4 Symbols and units

For the purposes of this International Standard, the following symbols and units apply. (See clause 3.)

	Symbol	Unit
heat flow rate	Φ	W
linear density of heat flow rate (heat flow rate per axial length)	Φ/L	W/m
areal density of heat flow rate (heat flow rate per area of a surface)	Φ/A	W/m^2
temperature of pipe surface	T_0	K
temperature of insulation outside surface	T_2	K
temperature of ambient air or gas	T_a	K
outer diameter of circular pipe	D_0	m
outer diameter of circular insulation	D_2	m
length of test section (in the axial direction)	L	m
area of specified surface	A	m^2
linear thermal conductance	Λ_l	W/(m·K)
linear thermal resistance	R_l	(m·K)/W
linear thermal transference	K_l	W/(m·K)
thermal conductivity	λ	W/(m·K)
thermal resistivity	r	(m·K)/W
surface coefficient of heat transfer of insulation outer surface	h_2	$W/(m^2 \cdot K)$
areal thermal conductance	Λ	$W/(m^2 \cdot K)$
areal thermal resistance	R	$(m^2 \cdot K)/W$
thickness of end cap beyond test pipe (in axial direction)	S	m
factor for Nukiyama calculation	n	

NOTES

7 The subscript "l" is used to denote linear properties (per unit axial length).

8 The subscript "cyl" is added to the symbols listed when it is important to indicate that the properties were derived from measurements on a pipe apparatus.

9 When both "l" and "cyl" subscripts are used together, they are written "l, cyl".

10 In ISO 7345, the linear density of heat flow rate and the areal density of heat flow rate are given the symbols q_l and q respectively. The more descriptive ratio symbols given here are used throughout this International Standard.

5 Requirements

5.1 Test specimens

Specimens may be rigid, semirigid or flexible (blanket-type), or may be loose-fill, suitably contained. They may be homogeneous or nonhomogeneous, isotropic or anisotropic, may include slits, joints or metallic elements and may include jackets or other coverings. Specimens shall be uniform in size and shape throughout their length (except for any intentional irregularities which occur well within the metered test section) and shall be designed for use on pipes of the same size as the test apparatus available. Generally, specimens will have a circular outside shape concentric with the bore; other outside shapes are allowed but only thermal transference may then be determined.

5.2 Operating temperature

The pipe may be operated at temperatures up to the maximum service temperature of the specimen or of the materials used in constructing the apparatus. The lower limit of the pipe temperature is determined by the restriction that it be sufficiently greater than the temperature of the specimen outer surface to provide the precision of measurement desired. Normally, the apparatus is operated in still air maintained at an ambient temperature of 15 °C to 35 °C, but this may be extended to other temperatures, other gases and other velocities. The outer specimen surface temperature may also be fixed by the use of a heated or cooled outer sheath or blanket or by the use of an additional layer of insulation. If a cold outer sheath or jacket is used, operation at low temperatures is possible provided that the pipe is maintained at a higher temperature.

5.3 Pipe size and shape

The test pipe shall have a circular cross-section.

5.4 Orientation

The test pipe normally has a horizontal orientation. Other orientations may be used but require special considerations because of possible convection effects both within and around the test pipe and the specimen.

5.5 Types of apparatus

Two distinctly different types of pipe apparatus are covered: the guarded end and the calibrated or calculated end types, which differ in the treatment of axial heat transfer at the ends of the test section. Specimens incorporating elements of high axial conductance, such as metallic jackets, shall be tested only on the guarded end type of apparatus.

5.6 Relevant properties

The linear thermal transference (defined in 3.1) can be calculated for all specimens and is the property most useful in quantifying pipe insulation performance. Knowing its value and the mean temperatures of the pipe and of the surrounding ambient air, the heat loss for a given length of insulated pipe can be directly calculated provided that the conditions in use are comparable with those of testing.

The thermal conductivity (see 3.5) is often used in specifications. In theory, it can be calculated only for homogeneous specimens of concentric circular shape which fit the test pipe tightly with no air gaps. In practice, it is often necessary to deviate from ideal conditions if errors introduced are judged to be acceptable. The thermal conductivity is useful in deriving the linear transference or other properties for insulation sizes different than that used for the measurement (see 6.2). The other properties defined in clause 3 may be used when specified and appropriate.

6 General considerations

6.1 Objectives

Two distinctly different objectives may be addressed as specified in 6.1.1 and 6.1.2. The specimen preparation and mounting depend on the choice of objective made by the user. Procedures aimed at either objective may be used and shall be fully reported.

6.1.1 End-use performance

If end-use performance data are desired, the specimen shall remain unaltered and be mounted in the same manner as would occur in normal application. In this case, the measured properties include the effects of any joints or slits, and of the resistance of any air gaps created by a loose fit on the pipe.

6.1.2 Material properties

If values of material properties are desired, the specimen shall be chosen or altered so that all pieces fit tightly together without open joints or slits and so that the specimen fits the test pipe tightly without an air space.

6.2 Application to other sizes

It is impractical to provide test apparatus to match the size of all pipe insulations manufactured. Thus it is necessary to calculate the properties for other sizes from data measured on a limited number of sizes of similar insulation. Procedures may differ depending on whether the specimen material and the test conditions are ideal or non-ideal.

Where end-use performance is measured including any air gap and/or imperfect fit, it is not permissible to calculate the properties for other sizes.

6.2.1 Ideal materials and conditions

For materials that are homogeneous with thermal conductivity either constant or a linear function of temperature and which are tested under uniform temperature conditions, it is possible to determine the thermal conductivity from a single test at a specific mean temperature using the relationship given in 3.5. This thermal conductivity may then be used to calculate the heat flow rate and other thermal transmission properties for other sizes of pipes, other thicknesses of insulation, and other temperature differences for the same material operating at the same mean temperature.

6.2.2 Non-ideal materials and conditions

In practice, many materials are not strictly homogeneous because

— their thermal conductivity is a complex function of temperature;

— during measurements the outer surface of the specimen is not at a uniform temperature due to heat transfer by convection and radiation; and/or

— an air gap can exist between the apparatus and the specimen.

A critical evaluation of the practical impact of these factors shall be made whenever data is to be extended to sizes and conditions other than those of the measurement.

Generally, measurements shall be made for a particular product or material on a minimum of two pipe sizes approximating to the range of interest. If the values of thermal conductivity from those measurements agree among themselves within acceptable limits, then their average may be used for calculation of other thermal transmission properties for other sizes in the range and for other conditions, for the products and mean temperature of the tests. If the measured thermal conductivities do not agree within acceptable limits, then suitable trend analyses shall be employed to determine the appropriate values of thermal conductivity pertinent to the sizes for which thermal transmission properties are to be obtained. If the measured thermal conductivities differ widely, then tests on additional sizes should be conducted. An alternative procedure is to interpolate between values of a measured transmission property (for example, thermal transference) from measurements taken on different pipe sizes but on the same thickness of insulation and at the same temperatures.

6.3 Required knowledge

Since it is impractical to include all details relating to the wide range of types of apparatus and procedures covered by this International Standard, users shall have appropriate prior knowledge and experience in thermal measurements.

6.4 Detailed instructions

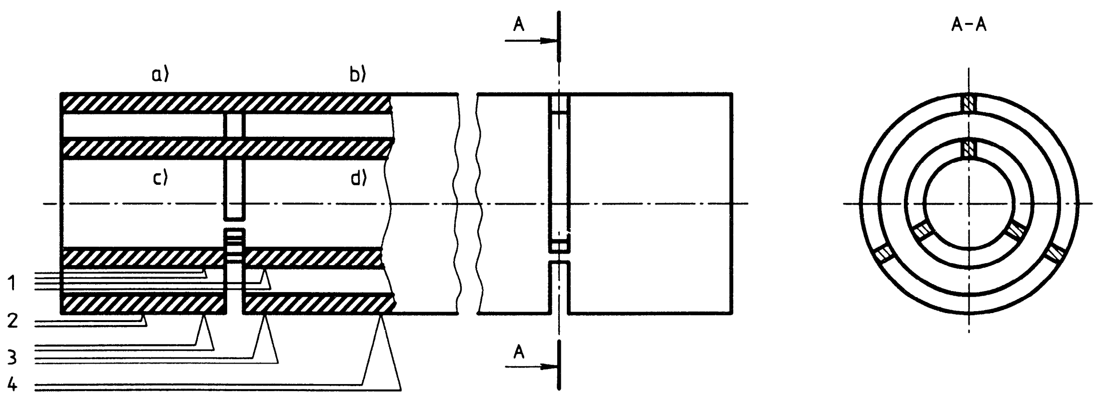
Users shall prepare detailed construction and operating instructions to aid builders and operators of specific apparatus to meet general requirements and objectives.

7 Apparatus

7.1 General requirements

The apparatus shall consist of the heated test pipe and instrumentation for controlling and measuring the pipe and ambient air temperatures, and the mean power dissipated in the test section heater. Instrumentation for the measurement of the insulation outer surface temperature shall also be included, unless only thermal transference is to be determined. The pipe shall be uniformly heated by an internal electric heater such as an electrical resistance winding on a separate internal pipe. In large apparatus it can be necessary to provide internal circulating fans or to fill the pipe with a heat transfer liquid to achieve uniform temperatures. Axial heat flow at the ends of the test section shall either be minimized by the use of separately heated guard sections (see 7.3 and figure 1) or by the use of insulated end caps and corrections applied to the measured quantity of heat (see 7.4 and figure 2). An enclosure or room equipped to control the temperature of the air surrounding the apparatus shall also be provided.

The apparatus shall conform to the principles and limitations set in this International Standard, but it is not intended in this method to include detailed requirements for the construction or operation of any particular apparatus. Such detailed instructions shall be prepared specifically for each apparatus.



Key

1 Monitoring thermocouples across gap of heater pipe
2 Guard measuring thermocouple
3 Monitoring thermocouples across gap of test pipe
4 Centre measuring thermocouple

a) Test pipe guard
b) Test pipe centre
c) Heater pipe guard
c) Heater pipe centre

Figure 1 — Guarded end apparatus

7.2 Dimensions

No restriction is placed on the apparatus pipe diameter, but the length of the test section shall be sufficient to ensure that the total measured heat flow is large enough, compared to end losses and to the accuracy of the power measurement, to achieve the desired test accuracy.

NOTE 11 For a guarded end apparatus (see 7.3) of 88,9 mm outside diameter, a test section length of 0,6 m, with a total specimen length of approximately 1 m has proven satisfactory. Calibrated or calculated end apparatus (see 7.4) of similar diameter usually suit specimen lengths of 2 m or more. These lengths can be unsatisfactory for some sizes of apparatus and for some test conditions, and estimates of the required length need to be made from appropriate error analysis.

As a convenience, the apparatus should be constructed to accept an integral number of standard lengths of insulation.

7.3 Guarded end apparatus

The guarded end apparatus (see figure 1) uses separately heated pipe sections, called "guards", located at each end of the metered test section which are maintained at the test section temperature to eliminate axial heat flow in the apparatus, and to aid in achieving uniform temperatures so that all heat flow in the specimen test section will be in the radial direction. Both test and guard section heaters shall be designed to achieve uniform temperatures over their lengths unless it has been shown that the expected deviation from temperature uniformity does not cause unacceptable errors in test results. Auxiliary heaters at the outside ends of single guards or a second guard, at each end, shall be used if required. The length of each guard section (or the combined length of double guards) shall be sufficient to limit, at each end of the test section, the combined axial heat flow in both apparatus and specimen to an acceptably small amount compared to the test section measured heat transfer rate.

NOTES

12 No known analysis exists for predicting the exact length of the guard sections or the degree of temperature uniformity necessary to achieve a desired accuracy of test results. It is hoped that such analysis will be forthcoming; in the meantime, apparatus should be designed with the same approximate geometrical ratios as those of existing proven apparatus and attempts should be made to achieve uniform temperatures over the guard lengths.

13 A guard section length of approximately 200 mm has been found satisfactory for apparatus of 88,9 mm outside diameter when testing specimens that are essentially homogeneous, are only moderately anisotropic and are of a thickness not greater than the pipe diameter. Longer guard sections may be required when testing thicker specimens or with specimens of high axial conductance.

A gap, normally not more than 4 mm in width, shall be provided between the guards and the test section, and between each guard section if double-guarded, in both the heater pipe and the test pipe (except for small bridges if needed for structural support). These gaps may be filled with material the thermal conductivity of which is much lower than that of the pipe.

Internal barriers shall be installed at each gap to minimize convection and radiation heat transfer between sections. Thermocouples, connected as differential thermopiles, shall be installed in the test pipe on both sides of each gap, and not more than 25 mm from the gap, for the purpose of monitoring the temperature differential across each gap. Thermocouples shall also be installed on any heater pipes or support members which provide a highly conductive path from test section to guard sections.

7.4 Calibrated or calculated end apparatus

The calibrated or calculated end apparatus (see figure 2) uses insulated caps at each end of the test section to minimize axial heat flow. Corrections for the end cap loss shall be determined either by direct calibration under the test conditions (the calibrated end apparatus) or by calculation using material properties (the calculated end apparatus). Internal electric heaters shall be designed to heat the test section uniformly over its length. If supplementary end heaters are used within the test section length, the power to such heaters shall be included in the measured test section power.

7.4.1 Calibrated end caps and calibrator pipe

For the calibrated end apparatus, the end caps shall have the same cross-sectional area as the test specimen and shall have approximately the same thermal transfer properties. Each end cap shall have a cavity of minimum depth equal to one half the test pipe diameter and of a size to accept the end of the test pipe. The calibrator pipe shall consist of a short section of the same pipe of a length equal to the combined cavity depth of the two end caps. It shall be fitted with internal heaters similar to those used in the test pipe including any supplementary end heaters. A minimum of four thermocouples spaced 90° apart shall be provided in the surface of the calibrator pipe to measure its temperature. They shall be of a wire size as small as practical but in no case larger than 0,64 mm diameter.