



Designation: C 1033 – 85 (Reapproved 2000)

Standard Test Method for Steady-State Heat Transfer Properties of Pipe Insulation Installed Vertically¹

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1. Scope

1.1 This test method covers the measurement of the steady-state heat transfer properties of pipe insulations for pipes operating at temperatures above the ambient environment from approximately 40°C to the maximum insulation design temperature. Specimens may be rigid, flexible, or loose-fill, may be homogeneous or nonhomogeneous, isotropic or nonisotropic, and of circular or noncircular cross section. Measurement of metallic reflective insulations is included in this test method; however, additional precautions must be taken when these materials are being evaluated.

1.2 When appropriate, or as required by specifications or other test methods, the following thermal transfer properties for the specimen can be calculated from the measured data (see 3.2):

1.2.1 The thermal resistance and conductance,

1.2.2 The thermal transference,

1.2.3 The surface resistance and heat transfer coefficient, and

1.2.4 The apparent thermal resistivity and conductivity.

1.3 This test method applies only for testing of insulations on vertical pipes, and the results will only apply for insulations installed vertically (see Note 1).

1.4 The test pipe may be of any size or shape provided that it matches the specimens to be tested. Normally the test method is used with circular pipes, however, its use is permitted with pipes or ducts of noncircular cross section (square, rectangular, hexagonal, etc.). One common size used for interlaboratory comparison is a pipe with an 88.9-mm outside diameter (standard nominal 80-mm, 3-in. pipe size).

1.5 This test method covers only the guarded-end type of pipe apparatus. No experience has been gathered with the calibrated or calculated-end pipe apparatus; therefore, this type of tester is not included as part of this specification.

1.6 The values stated in SI units are to be regarded as the standard. Conversion factors to other units are given in Table 1. The units used must accompany all numerical values.

NOTE 1—Measurement of insulations installed horizontally is covered in Test Method C 335 and Test Method C 691.

¹ This test method is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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NOTE 2—Discussions of the appropriateness of these properties to particular specimens or materials may be found in Test Method C 177, Test Method C 518, and in the literature.²

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 168 Terminology Relating to Thermal Insulating Materials³

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus³

C 302 Test Method for Density and Dimensions of Preformed Pipe-Covering-Type Thermal Insulation³

C 335 Test Method for Steady-State Heat Transfer Properties of Horizontal Pipe Insulations³

C 518 Test Method for Steady-State Heat Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus³

C 680 Practice for Determination of Heat Gain or Loss and the Surface Temperatures of Insulated Pipe and Equipment Systems by the Use of a Computer Program³

C 691 Test Method for Steady-State Thermal Transmission Properties of Nonhomogeneous Pipe Insulation Installed Horizontally⁴

C 870 Practice for Conditioning of Thermal Insulating Materials³

E 230 Temperature Electromotive Force (EMF) Tables for Standardized Thermocouples⁵

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology C 168.

3.2 *Definitions of Terms Specific to This Standard:*

² ASTM Subcommittee C16.30, "What Property Do We Measure," *Heat Transmission Measurements in Thermal Insulations*, ASTM STP 544, ASTM, 1974, pp. 5–12.

³ *Annual Book of ASTM Standards*, Vol 04.06.

⁴ Discontinued—See 1986 *Annual Book of ASTM Standards*, Vol 04.06.

⁵ *Annual Book of ASTM Standards*, Vol 14.03.

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TABLE 1 Conversion Factors (International Table)

NOTE 1—For thermal conductance per unit length or thermal transference per unit length, use the inverse of the table for thermal resistance per unit length. For thermal resistivity, use the inverse of the table for thermal conductivity. For thermal conductance (per unit area) or thermal transference (per unit area), use the inverse of the table for thermal resistance (per unit area).

Thermal Resistance per Unit Length ^A						
	K·m·W ^{-1(B)}	K·cm·W ⁻¹	K·cm·s·cal ⁻¹	K·m·h·kg·cal ⁻¹	°F·ft·h·Btu ⁻¹	
1 K·m·W ⁻¹ =	1.000	100.0	418.7	1.163	1.731	
1 K·cm·W ⁻¹ =	1.000 × 10 ⁻²	1.000	4.187	1.163 × 10 ⁻²	1.731 × 10 ⁻²	
1 K·cm·s·cal ⁻¹ =	2.388 × 10 ⁻³	0.2388	1.000	2.778 × 10 ⁻³	4.134 × 10 ⁻³	
1 K·m·h·kg·cal ⁻¹ =	0.8598	85.98	360.0	1.000	1.488	
1°F·ft·h·Btu ⁻¹ =	0.5778	57.78	241.9	0.6720	1.000	
Thermal Conductivity ^(A)						
	W·m ⁻¹ ·K ^{-1(B)}	W·cm ⁻¹ ·K ⁻¹	cal·s ⁻¹ ·cm ⁻¹ ·K ⁻¹	kg·cal·h ⁻¹ ·m ⁻¹ ·K ⁻¹	Btu·h ⁻¹ ·ft ⁻¹ ·°F ⁻¹	Btu·in. ⁻¹ ·h ⁻¹ ·ft ⁻² ·°F ⁻¹
1 W·m ⁻¹ ·K ⁻¹ =	1.000	1.000 × 10 ⁻²	2.388 × 10 ³	0.8598	0.5778	6.933
1 W·cm ⁻¹ ·K ⁻¹ =	100.0	1.000	0.2388	85.98	57.78	693.3
1 cal·s ⁻¹ ·K ⁻¹ =	418.7	4.187	1.000	360.0	241.9	2903.
1 kg·cal·h ⁻¹ ·K ⁻¹ =	1.163	1.163 × 10 ⁻²	2.778 × 10 ⁻³	1.000	0.6720	8.064
1 Btu·h ⁻¹ ·ft ⁻¹ ·°F ⁻¹ =	1.731	1.731 × 10 ⁻²	4.134 × 10 ⁻³	1.488	1.000	12.00
1 Btu·in. ⁻¹ ·h ⁻¹ ·ft ⁻² ·°F ⁻¹ =	0.1442	1.442 × 10 ⁻³	3.445 × 10 ⁻⁴	0.1240	8.333 × 10 ⁻²	1.000
Thermal Resistance per Unit Area ^A						
	K·m ² ·W ^{-1(B)}	K·cm ² ·W ⁻¹	K·cm ² ·s·cal ⁻¹	K·m ² ·h·kg·cal ⁻¹	°F·ft ² ·h·Btu ⁻¹	
1 K·m ² ·W ⁻¹ =	1.000	1.000 × 10 ⁴	4.187 × 10 ⁴	1.163	5.678	
1 K·cm ² ·W ⁻¹ =	1.000 × 10 ⁻⁴	1.000	4.187	1.163 × 10 ⁻⁴	5.678 × 10 ⁻⁴	
1 K·cm ² ·s·cal ⁻¹ =	2.388 × 10 ⁻⁵	0.2388	1.000	2.778 × 10 ⁻⁵	1.356 × 10 ⁻⁴	
1 K·m ² ·h·kg·cal ⁻¹ =	0.8598	8.594 × 10 ³	3.600 × 10 ⁴	1.000	4.882	
1°F·ft ² ·h·Btu ⁻¹ =	0.1761	1.761 × 10 ³	7.373 × 10 ³	0.2048	1.000	

^A Units are given in terms of (1) the absolute joule per second or watt, (2) the calorie (International Table) = 4.1868 J, or the British thermal unit (International Table) = 1055.06 J.

^B This is the SI (International System of Units) unit.

3.2.1 *pipe insulation thermal conductance, C*—the steady-state time rate of heat flow per unit pipe area divided by the difference between the average pipe surface temperature and the average insulation outer surface temperature. It is the reciprocal of the pipe insulation thermal resistance, *R*.

$$C = \frac{Q}{A_o(t_o - t_2)} = \frac{1}{R} \quad (1)$$

3.2.2 *pipe insulation thermal resistance, R*—the average temperature difference between the pipe surface and the insulation outer surface required to produce a steady-state unit time rate of heat flow per unit of pipe area. It is the reciprocal of the pipe insulation thermal conductance, *C*.

$$R = \frac{A_o(t_o - t_2)}{Q} = \frac{1}{C} \quad (2)$$

3.2.3 *pipe insulation thermal transference, T_r*—the steady-state time rate of heat flow per unit pipe area divided by the difference between the average pipe surface temperature and the average air ambient temperature. It is a measure of the heat transferred through the insulation to the ambient environment.

$$T_r = \frac{Q}{A_o(t_o - t_a)} \quad (3)$$

3.2.4 *surface heat transfer coefficient, h₂*—the ratio of the steady-state time rate of heat flow per unit surface area to the average temperature difference between the surface and the ambient surroundings. The inverse of the surface heat transfer

coefficient is the surface resistance. For circular cross sections:

$$h_2 = \frac{Q}{A_2(t_2 - t_a)} \quad (4)$$

3.2.5 *pipe insulation apparent thermal conductivity, λ*—of homogeneous material, the ratio of the steady-state time rate of heat flow per unit area to the average temperature gradient (temperature difference per unit distance of heat flow path). It includes the effect of the fit upon the test pipe and is the reciprocal of the pipe insulation apparent thermal resistivity, *r*. For pipe insulation of circular cross section, the pipe insulation apparent thermal conductivity is:

$$\lambda = \frac{Q \ln(r_2/r_o)}{L 2\pi(t_o - t_2)} = \frac{1}{r} \quad (5)$$

3.2.6 *pipe insulation apparent thermal resistivity, r*—of homogeneous material, the ratio of the average temperature gradient (temperature difference per unit distance of heat flow path) to the steady-state time rate of heat flow per unit area. It includes the rate of heat flow per unit area. It includes the effect of the fit upon the test pipe and is the reciprocal of the pipe insulation apparent thermal conductivity, *λ*. For pipe insulation of circular cross section, the pipe insulation apparent thermal resistivity is:

$$r = \frac{2\pi L(t_o - t_2)}{Q \ln(r_2/r_o)} = \frac{1}{\lambda} \quad (6)$$

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3.3 Symbols: (see 1.6):

C	= pipe insulation thermal conductance, $\text{W/m}^2\cdot\text{K}$,
R	= pipe insulation thermal resistance, $\text{K}\cdot\text{m}^2/\text{W}$,
T_r	= pipe insulation thermal transference, $\text{W/m}^2\cdot\text{K}$,
λ	= pipe insulation apparent thermal conductivity, $\text{W/m}\cdot\text{K}$,
r	= pipe insulation apparent thermal resistivity, $\text{K}\cdot\text{m}/\text{W}$,
h_2	= surface heat transfer coefficient of insulation outer surface, $\text{W/m}^2\cdot\text{K}$,
Q	= time rate of heat flow in test section, W ,
t_o	= temperature of pipe surface, K ,
t_1	= temperature of insulation inside surface, K ,
t_2	= temperature of insulation outside surface, K ,
t_a	= temperature of ambient air or gas, K ,
r_o	= outer radius of circular pipe, m ,
r_1	= inner radius of circular insulation, m ,
r_2	= outer radius of circular insulation, m ,
L	= length of test section (see 9.1.1), m ,
A_o	= area of pipe test section surface, m^2 , and
A_2	= area of external surface of specimen test section, m .

4. Significance and Use

4.1 As determined by this test method, the pipe thermal resistance or conductance (and, where applicable, the apparent thermal resistivity or conductivity) are means of comparing insulations that include the effects of the insulation and its fit upon the pipe but do not include the effects of the outer surface resistance or heat transfer coefficient. They are thus appropriate when the insulation outer surface temperature and the pipe temperature are known or specified. The pipe thermal transference incorporates both the effect of the insulation and its fit upon the pipe and also the effect of the surface heat transfer coefficient. It is appropriate when the ambient conditions and the pipe temperature are known or specified and the thermal effects of the surface are to be included.

4.2 The thermal properties determined by this test method are not true material properties since they include the effects of the fit upon the pipe (including the air space resistances), orientation, and the effect of any longitudinal and circumferential joints. Therefore, properties determined by this test method may be somewhat different than that obtained on apparently similar material in flat form using the guarded hot plate, Test Method C 177, or the heat flow meter apparatus, Test Method C 518, or similar material in pipe form using Test Method C 335.

4.3 Because of the test condition requirements prescribed in this test method, it should be recognized that the thermal transfer properties obtained will not necessarily be the value pertaining under all service conditions. As an example, the test method provides that the thermal properties shall be obtained by tests on dry or conditioned specimens, while such a condition may not be realized in service. The results obtained are strictly applicable only for the conditions of test and for the product construction tested, and must not be applied without proper adjustment when the material is used at other conditions, such as mean temperatures that differ appreciably from those of the test. With these qualifications in mind, the following apply:

4.3.1 For vertical pipes of the same size and temperature, operating in the same ambient environment, values obtained by this test method may be used for the intercomparison of several specimens, for comparison to specification values, and for estimating heat loss of actual applications of specimens identical to those tested (including any jackets, joints, or surface treatments). For such use, it may be necessary to correct for the effect of end joints and other recurring irregularities (see 4.6).

4.3.2 When applying the results to insulation sizes and thicknesses different from those used in the test, an appropriate mathematical analysis is required. For homogeneous materials, this may consist of the use of the thermal conductivity or resistivity values (corrected for any changes in mean temperature) plus the use of the surface heat transfer coefficient when the ambient temperature is considered (for example, see Practice C 680). For nonhomogeneous and reflective insulation materials, a more detailed mathematical model is required which properly accounts for the individual modes of heat transfer (conduction, convection, radiation) and the variation of each mode with changing pipe size, insulation thickness, temperature, and orientation.

4.4 It is difficult to measure the thermal performance of reflective insulations which incorporate air cavities, since the geometry and orientation of the air cavities can affect convective heat transfer. While it is always desirable to test full length pipe sections, this is not always possible due to size limitations of existing pipe insulation testers. If insulation sections are tested less than full length, internal convective heat transfer may be altered, which would affect the measured performance. Therefore, it must be recognized that the measured thermal performance of less than full length insulation sections may not represent that of full length sections.

4.5 The design of the guarded-end pipe apparatus is based upon negligible heat flow across the guard gaps in both the insulation specimen and the test pipe. Some nonhomogeneous and reflective insulations may have to be modified at the end over the guard gap in order to prevent axial heat flow. While these modifications are not desirable and should be avoided, for some nonhomogeneous insulation designs, they provide the only means to satisfy the negligible heat flow assumption across the guard gaps. Therefore, thermal performance measured on insulation specimens with modified ends may not represent the performance of standard insulation sections.

4.6 This test method may be used to determine the effect of end joints or other isolated irregularities by comparing tests of two specimens, one of which is uniform throughout its length and the other which contains the joint or other irregularity within the test section. The difference in heat loss between these two tests, corrected for the uniform area covered by the joint or other irregularity, is the extra heat loss introduced. Care must be taken that the tests are performed under the same conditions of pipe and ambient temperature and that sufficient length exists between the joint or irregularity and the test section ends to prevent appreciable end loss.

4.7 To assure satisfactory results in the use of this test method, the principles governing the size, construction, and use of apparatus described in this test method should be followed. If the results are to be reported as the average of