



Designation: C 335 – 03a

Standard Test Method for Steady-State Heat Transfer Properties of Horizontal Pipe Insulation¹

This standard is issued under the fixed designation C 335; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the measurement of the steady-state heat transfer properties of pipe insulations installed on a horizontal test pipe operating at temperatures above ambient. Specimens may be rigid, flexible, or loose fill, may be homogeneous or nonhomogeneous, isotropic or nonisotropic, and of circular or non-circular cross section. Measurement of metallic reflective insulation and mass insulations with metal jackets or other elements of high axial conductance is included; however, additional precautions must be taken and specified special procedures must be followed.

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 pipe insulation lineal thermal resistance and conductance,

1.2.2 The pipe insulation lineal thermal transference,

1.2.3 The surface areal resistance and heat transfer coefficient,

1.2.4 The thermal resistivity and conductivity,

1.2.5 The areal thermal resistance and conductance, and

1.2.6 The areal thermal transference.

NOTE 1—In this test method the preferred resistance, conductance, and transference are the lineal values computed for a unit length of pipe. These must not be confused with the corresponding areal properties computed on a unit area basis which are more applicable to flat slab geometry. If these areal properties are computed, the area used in their computation must be reported.

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 (1).²

1.3 This test method allows for operation over a wide range of temperatures. The upper limit of the pipe surface tempera-

ture is determined by the maximum service temperature of the specimen or of the materials used in constructing the apparatus. The lower limit 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 closely controlled still air ambient from 15 to 30°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 uniform layer of insulation.

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 a circular cross section of 88.9-mm diameter (standard nominal 80-mm (3-in.) pipe size), although several other sizes are reported in the literature (2-4).

1.5 The test method applies only to test pipes with a horizontal axis. Other orientations, such as vertical, require special precautions, which are being considered for a separate method.

1.6 This test method covers two distinctly different types of pipe apparatus, the guarded-end and the calibrated or calculated-end types, which differ in the treatment of axial heat transfer at the end of the test section.

1.6.1 The guarded-end apparatus utilizes separately heated guard sections at each end, which are controlled at the same temperature as the test section to limit axial heat transfer. This type of apparatus may be used for all types of specimens within the scope of this test method and must be used for specimens incorporating elements of high axial conductance, such as reflective insulations or metallic jackets.

1.6.2 The calibrated or calculated-end apparatus utilizes insulated end caps at each end of the test section to minimize axial heat transfer. Corrections, based either on calibration of the end caps under the conditions of test or on calculations using known material properties, are applied to the measured test section heat transfer. These apparatuses are not applicable for tests on specimens with elements of high axial conductance

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.

Current edition approved December 1, 2003. Published January 2004. Originally approved in 1954. Last previous edition approved in 2003 as C 335 – 03.

² The boldface numbers in parentheses refer to the references at the end of this test method.

such as reflective insulations or metallic jackets whose effect may not be adequately covered by calibration or calculation.

1.7 SI units are standard for this test method. Conversion factors to other units are given in **Table 1**. The units used must accompany all numerical values.

1.8 *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:³

C 168 Terminology Relating to Thermal Insulation

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

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

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

C 680 Practice for Estimate of Heat Gain or Loss, and Surface Temperature of Insulated Flat, Cylindrical, and Spherical Systems by the Use of a Computer Program

C 870 Practice for Conditioning of Thermal Insulating Materials

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

C 1045 Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions

E 230 Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples

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:*

3.2.1 *areal thermal conductance, C*—the steady-state time rate of heat flow per unit area of a specified surface (**Note 3**) divided by the difference between the average pipe surface temperature and the average insulation outer surface temperature. It is the reciprocal of the areal thermal resistance, *R*.

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

where the surface of the area, *A*, must be specified (usually the pipe surface or sometimes the insulation outer surface).

NOTE 3—The value of *C*, 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 may be defined as in **3.2.7** (Eq 8), the areal conductance, *C*, is given as follows:

$$C = \frac{2\pi L \lambda_p}{A \ln(r_2/r_o)} \quad (2)$$

If the area is specially chosen to be the “log mean area,” equal to $2L(r_2 - r_o)/\ln(r_2/r_o)$, then $C = \lambda_p/(r_2 - r_o)$. Since $(r_2 - r_o)$ 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 defined in **3.2.2**. Since

TABLE 1 Conversion Factors (International Table)

NOTE—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} ·cm ^{−1} ·K ^{−1} =	418.7	4.187	1.000	360.0	241.9	2903.
1 kg·cal·h ^{−1} ·m ^{−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.

these areal coefficients are arbitrary, and since the area used is often not stated, thus leading to possible confusion, it is recommended that these areal coefficients not be used unless specifically requested.

3.2.2 *areal thermal resistance, R* —the average temperature difference between the pipe surface and the insulation outer surface required to produce a steady-state unit rate of heat flow per unit area of a specified surface (Note 3). It is the reciprocal of the areal thermal conductance, C .

$$R = \frac{A(t_o - t_2)}{Q} = \frac{1}{C} \quad (3)$$

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

3.2.3 *areal thermal transference, T_r* —the time rate of heat flow per unit surface area of the insulation divided by the difference between the average pipe surface temperature and the average air ambient temperature.

$$T_r = \frac{Q}{2\pi r_2 L(t_o - t_a)} \quad (4)$$

3.2.4 *pipe insulation lineal thermal conductance, C_p* —the steady-state time rate of heat flow per unit pipe insulation length 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 lineal thermal resistance, R_p .

$$C_p = \frac{Q}{L(t_o - t_2)} = \frac{1}{R_p} \quad (5)$$

3.2.5 *pipe insulation lineal thermal resistance, R_p* —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 insulation length. It is the reciprocal of the pipe insulation lineal thermal conductance, C_p .

$$R_p = \frac{L(t_o - t_2)}{Q} = \frac{1}{C_p} \quad (6)$$

3.2.6 *pipe insulation lineal thermal transference, T_{r_p}* —the steady-state time rate of heat flow per unit pipe insulation length 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.

$$T_{r_p} = \frac{Q}{L(t_o - t_a)} \quad (7)$$

3.2.7 *pipe insulation thermal conductivity, λ_p* —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 thermal resistivity, r_p . For pipe insulation of circular cross section, the pipe insulation thermal conductivity is:

$$\lambda_p = \frac{Q \ln(r_2/r_o)}{L 2\pi(t_o - t_2)} = \frac{1}{r_p} \quad (8)$$

3.2.8 *pipe insulation thermal resistivity, r_p* —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 effect of the fit upon the test pipe and is the reciprocal of the pipe insulation thermal conductivity, λ_p . For pipe insulation of circular cross section, the pipe insulation thermal resistivity is calculated as follows:

$$r_p = \frac{2\pi L(t_o - t_2)}{Q \ln(r_2/r_o)} = \frac{1}{\lambda_p} \quad (9)$$

3.2.9 *surface areal heat transfer coefficient, h_2* —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:

$$h_2 = \frac{Q}{2\pi r_2 L(t_2 - t_a)} \quad (10)$$

3.3 *Symbols: Symbols see 1.7:*

C_p	= pipe insulation lineal thermal conductance, W/m·K,
R_p	= pipe insulation lineal thermal resistance, K·m/W,
T_{r_p}	= pipe insulation lineal thermal transference, W/m·K,
λ_p	= pipe insulation thermal conductivity, W/m·K,
r_p	= pipe insulation thermal resistivity, K·m/W,
h_2	= surface areal heat transfer coefficient of insulation outer surface, W/m ² ·K,
C	= areal thermal conductance, W/m ² ·K,
R	= areal thermal resistance, K·m ² /W,
T_r	= areal thermal transference, W/m ² ·K,
Q	= time rate of heat flow to the test section of length L , 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, and
A	= area of specified surface, m ² .

4. Significance and Use

4.1 As determined by this test method, the pipe insulation lineal thermal resistance or conductance (and, when applicable, the thermal resistivity or conductivity) are means of comparing insulations which include the effects of the insulation and its fit upon the pipe, circumferential and longitudinal jointing, and variations in construction, 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. However, since the thermal properties determined by this test method include the effects of fit and jointing, they are not true material properties. Therefore, properties determined by this test method may be somewhat different from those 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.

4.2 The pipe insulation lineal 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.

4.3 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, this 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 horizontal 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 engineering data for estimating heat loss of actual applications of specimens identical to those tested (including any jackets or surface treatments). For such use, it may be necessary to correct for the effect of end joints and other recurring irregularities (4.4).

4.3.2 When applying the results to insulation sizes 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, and temperature.

4.4 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.

4.5 For satisfactory results in conformance with this test method, the principles governing construction and use of apparatus described in this test method should be followed. If the results are to be reported as having been obtained by this test method, then all the pertinent requirements prescribed in this test method shall be met or any exceptions shall be described in the report.

4.6 It is not practical in a test method of this type to establish details of construction and procedure to cover all

contingencies that might offer difficulties to a person without technical knowledge concerning the theory of heat flow, temperature measurements, and general testing practices. Standardization of this test method does not reduce the need for such technical knowledge. It is recognized also that it would be unwise to restrict the further development of improved or new methods or procedures by research workers because of standardization of this test method.

NOTE 4—When testing at ambient temperatures below normal room temperatures, theoretical analysis shows that the experimental heat flow direction is unimportant for a perfectly homogenous material. However, if the insulation's properties vary in the radial direction, the experimental heat flow direction will significantly affect the measured thermal conductivity. Therefore great care should be exercised when using data from a radial heat flow outward experiment for a radial heat flow inward application.

5. Apparatus

5.1 The apparatus shall consist of the heated test pipe and instrumentation for measuring the pipe and insulation surface temperatures, the average ambient air temperature, and the average power dissipated in the test section heater. The pipe shall be uniformly heated by an internal electric heater (Notes 5 and 6). In large apparatus it may be advantageous to provide internal circulating fans or to fill the pipe with a heat transfer fluid to achieve uniform temperatures. The guarded end design also requires, at each end of the test section, a short section of pipe with its own separately controlled heater (see 5.3 and Fig. 1) while the calibrated or calculated-end design requires suitable insulated caps at each end (see 5.4 and Fig. 2). An essential requirement of the test is an enclosure or room equipped to control the temperature of the air surrounding the apparatus. The apparatus shall conform to the principles and limitations prescribed in the following sections, but it is not intended in this test method to include detailed requirements for the construction or operation of any particular apparatus.⁴

NOTE 5—Experiments have been reported that use an electrically heated cylindrical screen rather than an internally heated pipe (5). While these designs and the accompanying analysis are not included in this test method, their findings are pertinent to this standard.

NOTE 6—The most commonly used heater consists of an insulated electrical resistance wire or ribbon on the surface or in the grooves of a separate pipe, internal to the test pipe. This heater pipe may either be a snug fit inside the test pipe, in which case the contact must be uniform to achieve uniform test pipe temperatures, or the heater pipe may be smaller so that heat is transferred across a uniform air gap. In this standard the combination of heater winding and heater pipe will be called either a "heater" or a "heater pipe."

5.2 *Apparatus Pipe*, no restriction is placed on the cross section size or shape, but the length of the test section must be sufficient to ensure that the total measured heat flow is large enough, when compared to end losses and to the accuracy of the power measurement, to achieve the desired test accuracy (see 5.3 and 9.4). A test section length of approximately 0.5 m has proven satisfactory for an apparatus with a circular

⁴ Documents showing details of both guarded-end and calibrated-end apparatus complying with the requirements of this method are available from ASTM for a nominal fee. Order Adjunct: ADJC033501 for the Guarded-End Apparatus and Adjunct: ADJC033502 for the Calibrated-End Cap Apparatus.