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Standard Test Method for Steady-State Heat Transfer Properties of Pipe Insulation[1]

This standard is issued under the fixed designation C335/C335M; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This test method covers the measurement of the steady-state heat transfer properties of pipe insulations. Specimen types include rigid, flexible, and loose fill; homogeneous and nonhomogeneous; isotropic and nonisotropic; 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 The test apparatus for this purpose is a guarded-end or calibrated-end pipe apparatus. The guarded-end apparatus is a primary (or absolute) method. The guarded-end method is comparable, but not identical to ISO 8497. The ISO method does not use the calculation procedure in Practice C1045.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 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):

1.4.1 The pipe insulation lineal thermal resistance and conductance,

1.4.2 The pipe insulation lineal thermal transference,

1.4.3 The surface areal resistance and heat transfer coefficient,

1.4.4 The thermal resistivity and conductivity,

1.4.5 The areal thermal resistance and conductance, and

1.4.6 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 C177, Test Method C518, and in the literature (**1**).[2]

1.5 This test method allows for operation over a wide range of temperatures. The upper and lower limit of the pipe surface temperature is determined by the maximum and minimum service temperature of the specimen or of the materials used in constructing the apparatus. In any case, the apparatus must be operated such that the temperature difference between the exposed surface and the ambient is sufficiently large enough to provide the precision of measurement desired. Normally the apparatus is operated in closely controlled still air ambient from 15 to 30°C, but other temperatures, other gases, and other velocities are acceptable. It is also acceptable to control the outer specimen surface temperature by the use of a heated or cooled outer sheath or blanket or by the use of an additional uniform layer of insulation.

1.6 The use any size or shape of test pipe is allowable 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**).

1.7 The test method applies only to test pipes with a horizontal or vertical axis. For the horizontal axis, the literature includes using the guarded-end, the calibrated, and the calibrated-end cap methods. For the vertical axis, no experience has been found to support the use of the calibrated or calibrated-end methods. Therefore the method is restricted to using the guarded-end pipe apparatus for vertical axis measurements.

1.8 This test method covers two distinctly different types of pipe apparatus, the guarded-end and the calibrated or

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

calculated-end types, which differ in the treatment of axial heat transfer at the end of the test section.

1.8.1 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 is preferred for all types of specimens within the scope of this test method and must be used for specimens incorporating elements of high axial conductance.

1.8.2 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 the 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 such as reflective insulations or metallic jackets. There is no known experience on using these apparatuses for measurements using a vertical axis.

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C168 Terminology Relating to Thermal Insulation

C177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus

C302 Test Method for Density and Dimensions of Preformed Pipe-Covering-Type Thermal Insulation

C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus

C680 Practice for Estimate of the Heat Gain or Loss and the Surface Temperatures of Insulated Flat, Cylindrical, and Spherical Systems by Use of Computer Programs

C870 Practice for Conditioning of Thermal Insulating Materials

C1045 Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions

C1058 Practice for Selecting Temperatures for Evaluating and Reporting Thermal Properties of Thermal Insulation

E230 Specification for Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples

[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.

2.2 *ISO Standards:*

ISO 8497 Thermal Insulation-Dermination of Steady State Thermal Transmission Properties of Thermal Insulation for Circular Pipes

3. Terminology

3.1 *Definitions*—For definitions of terms used in this test method, refer to Terminology C168.

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 is 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 $2\pi L\ (r_2 - r_o)/\ln(r_2/r_o)$, 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 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_L*—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_L.

$$C_L = \frac{Q}{L(t_o - t_2)} = \frac{1}{R_L} \tag{5}$$

3.2.5 *pipe insulation lineal thermal resistance,* R_L—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_L.

$$R_L = \frac{L(t_o - t_2)}{Q} = \frac{1}{C_L} \tag{6}$$

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.

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

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_L. For pipe insulation of circular cross section, the pipe insulation thermal conductivity is:

$$\lambda_p = \frac{Q \ 1n\left(r_2/r_o\right)}{L2\pi(t_o - t_2)} = \frac{1}{r_L} \tag{8}$$

3.2.8 *pipe insulation thermal resistivity,* r_L—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:

$$r_L = \frac{2\pi L(t_o - t_2)}{Q \ 1n\left(r_2/r_o\right)} = \frac{1}{\lambda_p} \tag{9}$$

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:

$$h_2 = \frac{Q}{2\pi r^2 L(t_2 - t_a)} \tag{10}$$

3.3 *Symbols:* see 1.3:

C_L = pipe insulation lineal thermal conductance, W/m·K [Btu · in/F · hr · ft^2],
R_L = pipe insulation lineal thermal resistance, K·m/W [Btu · in/F · hr · ft^2],
T_{r_p} = pipe insulation lineal thermal transference, W/m·K [Btu · in/F · hr · ft^2],
λ_p = pipe insulation thermal conductivity, W/m·K [Btu · in/F · hr · ft^2],
r_L = pipe insulation thermal resistivity, K·m/W [F · hr · ft^2],
h_2 = surface areal heat transfer coefficient of insulation outer surface, W/m^2·K [Btu · in/F · hr · ft^2],
C = areal thermal conductance, W/m^2·K [Btu · in/F · hr · ft^2],
R = areal thermal resistance, K·m^2/W [F · hr · ft^2],
T_r = areal thermal transference, W/m^2·K [Btu · in/F · hr · ft^2],
Q = time rate of heat flow to the test section of length L, W [Btu/hr],
t_o = temperature of pipe surface, K [F],
t_1 = temperature of insulation inside surface, K [F],
t_2 = temperature of insulation outside surface, K [F],
t_a = temperature of ambient air or gas, K [F],
r_o = outer radius of circular pipe, m [ft],
r_1 = inner radius of circular insulation, m [ft],
r_2 = outer radius of circular insulation, m ft],
L = length of test section (see 8.1.1), m [ft], and
A = area of specified surface, m^2 [ft^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 are somewhat different from those obtained on apparently similar material in flat form using the guarded hot plate, Test Method C177, or the heat flow meter apparatus, Test Method C518.

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, recognize 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 conditions are not necessarily 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 or vertical pipes of the same size and temperature, operating in the same ambient environment,