Designation: C177 – 13

Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus[1]

This standard is issued under the fixed designation C177; 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 establishes the criteria for the laboratory measurement of the steady-state heat flux through flat, homogeneous specimen(s) when their surfaces are in contact with solid, parallel boundaries held at constant temperatures using the guarded-hot-plate apparatus.

1.2 The test apparatus designed for this purpose is known as a guarded-hot-plate apparatus and is a primary (or absolute) method. This test method is comparable, but not identical, to ISO 8302.

1.3 This test method sets forth the general design requirements necessary to construct and operate a satisfactory guarded-hot-plate apparatus. It covers a wide variety of apparatus constructions, test conditions, and operating conditions. Detailed designs conforming to this test method are not given but must be developed within the constraints of the general requirements. Examples of analysis tools, concepts and procedures used in the design, construction, calibration and operation of a guarded-hot-plate apparatus are given in Refs (**1-41**).[2]

1.4 This test method encompasses both the single-sided and the double-sided modes of measurement. Both distributed and line source guarded heating plate designs are permitted. The user should consult the standard practices on the single-sided mode of operation, Practice C1044, and on the line source apparatus, Practice C1043, for further details on these heater designs.

1.5 The guarded-hot-plate apparatus can be operated with either vertical or horizontal heat flow. The user is cautioned however, since the test results from the two orientations may be different if convective heat flow occurs within the specimens.

1.6 Although no definitive upper limit can be given for the magnitude of specimen conductance that is measurable on a guarded-hot-plate, for practical reasons the specimen conductance should be less than 16 $W/(m^2K)$.

1.7 This test method is applicable to the measurement of a wide variety of specimens, ranging from opaque solids to porous or transparent materials, and a wide range of environmental conditions including measurements conducted at extremes of temperature and with various gases and pressures.

1.8 Inhomogeneities normal to the heat flux direction, such as layered structures, can be successfully evaluated using this test method. However, testing specimens with inhomogeneities in the heat flux direction, such as an insulation system with thermal bridges, can yield results that are location specific and shall not be attempted with this type of apparatus. See Test Method C1363 for guidance in testing these systems.

1.9 Calculations of thermal transmission properties based upon measurements using this method shall be performed in conformance with Practice C1045.

1.10 In order to ensure the level of precision and accuracy expected, persons applying this standard must possess a knowledge of the requirements of thermal measurements and testing practice and of the practical application of heat transfer theory relating to thermal insulation materials and systems. Detailed operating procedures, including design schematics and electrical drawings, should be available for each apparatus to ensure that tests are in accordance with this test method. In addition, automated data collecting and handling systems connected to the apparatus must be verified as to their accuracy. This can be done by calibration and inputting data sets, which have known results associated with them, into computer programs.

1.11 It is not practical for a test method of this type to establish details of design and construction and the procedures to cover all contingencies that might offer difficulties to a person without technical knowledge concerning theory of heat flow, temperature measurements and general testing practices. The user may also find it necessary, when repairing or

---

[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 Sept. 15, 2013. Published October 2013. Originally approved in 1942. Last previous edition approved in 2010 as C177 – 10 . DOI: 10.1520/C0177-13.

[2] The boldface numbers given in parentheses refer to the list of references at the end of this standard.

modifying the apparatus, to become a designer or builder, or both, on whom the demands for fundamental understanding and careful experimental technique are even greater. Standardization of this test method is not intended to restrict in any way the future development of new or improved apparatus or procedures.

1.12 This test method does not specify all details necessary for the operation of the apparatus. Decisions on sampling, specimen selection, preconditioning, specimen mounting and positioning, the choice of test conditions, and the evaluation of test data shall follow applicable ASTM Test Methods, Guides, Practices or Product Specifications or governmental regulations. If no applicable standard exists, sound engineering judgment that reflects accepted heat transfer principles must be used and documented.

1.13 This test method allows a wide range of apparatus design and design accuracy to be used in order to satisfy the requirements of specific measurement problems. Compliance with this test method requires a statement of the uncertainty of each reported variable in the report. A discussion of the significant error factors involved is included.

1.14 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.15 *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.* Specific precautionary statements are given in Note 21.

1.16 Major sections within this test method are arranged as follows:

2. Referenced Documents

2.1 *ASTM Standards:*[3]

C168 Terminology Relating to Thermal Insulation

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

C687 Practice for Determination of Thermal Resistance of Loose-Fill Building Insulation

C1043 Practice for Guarded-Hot-Plate Design Using Circular Line-Heat Sources

C1044 Practice for Using a Guarded-Hot-Plate Apparatus or Thin-Heater Apparatus in the Single-Sided Mode

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

C1363 Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus

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

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

2.2 *ISO Standard:*

ISO 8302 Thermal Insulation—Determination of Steady-State Areal Thermal Resistance and Related Properties—Guarded-Hot-Plate Apparatus[4]

2.3 *ASTM Adjuncts:*ASTM

Table of Theoretical Maximum Thickness of Specimens and Associated Errors[5]

Descriptions of Three Guarded-Hot-Plate Designs[5]

Line-Heat-Source Guarded Hot-Plate Apparatus[6]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms and symbols used in this test method, refer to Terminology C168 and the following subsections.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *auxiliary cold surface assembly, n*—the plate that provides an isothermal boundary at the outside surface of the auxiliary insulation.

3.2.2 *auxiliary insulation, n*—insulation placed on the back side of the hot-surface assembly, in place of a second test specimen, when the single sided mode of operation is used. (*Synonym*—backflow specimen.)

3.2.3 *cold surface assembly, n*—the plates that provide an isothermal boundary at the cold surfaces of the test specimen.

[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.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[5] Available from ASTM Headquarters, Order Adjunct: ADJC0177.

[6] Available from ASTM Headquarters, Order Adjunct: ADJC1043.

3.2.4 *controlled environment, n*—the environment in which an apparatus operates.

3.2.5 *guard, n*—promotes one-dimensional heat flow. Primary guards are planar, additional coplanar guards can be used and secondary or edge guards are axial.

3.2.6 *guarded-hot-plate apparatus, n*—an assembly, consisting of a hot surface assembly and two isothermal cold surface assemblies.

3.2.7 *guarded-hot-plate, n*—the inner (rectangular or circular) plate of the hot surface assembly, that provides the heat input to the metered section of the specimen(s).

3.2.8 *hot surface/assembly, n*—the complete center assembly providing heat to the specimen(s) and guarding for the meter section.

3.2.9 *metered section, n*—the portion of the test specimen (or auxiliary insulation) through which the heat input to the guarded-hot-plate flows under ideal guarding conditions.

3.2.10 *mode, double-sided, n*—operation of the guarded-hot-plate apparatus for testing two specimens, each specimen placed on either side of the hot surface assembly.

3.2.11 *mode, single-sided, n*—operation of the guarded-hot-plate apparatus for testing one specimen, placed on one side of the hot-surface assembly.

3.2.12 *thermal transmission properties, n*—those properties of a material or system that define the ability of a material or system to transfer heat such as thermal resistance, thermal conductance, thermal conductivity and thermal resistivity, as defined by Terminology C168.

3.3 *Symbols*—The symbols used in this test method have the following significance:

3.3.1 ρ_m—specimen metered section density, kg/m^3.

3.3.2 ρ_s—specimen density, kg/m^3.

3.3.3 λ—thermal conductivity, W/(m K).

3.3.4 σ—Stefan-Boltzmann constant, W/m^2 K^4.

3.3.5 A—metered section area normal to heat flow, m^2.

3.3.6 A_g—area of the gap between the metered section and the primary guard, m^2.

3.3.7 A_m—area of the actual metered section, m^2.

3.3.8 A_s—area of the total specimen, m^2.

3.3.9 C—thermal conductance, W/(m^2 K).

3.3.10 C_i—the specific heat of the *i*th component of the metered section, J/(kg K).

3.3.11 dT/dt—potential or actual drift rate of the metered section, K/s.

3.3.12 λ_g—thermal conductivity of the material in the primary guard region, W/(m K).

3.3.13 L—in-situ specimen thickness, m.

3.3.14 m—mass of the specimen in the metered section, kg.

3.3.15 m_i—the mass of the *i*th component, kg.

3.3.16 m_s—mass of the specimen, kg.

3.3.17 Q—heat flow rate in the metered section, W.

3.3.18 q—heat flux (heat flow rate per unit area), Q, through area, A, W/m^2.

3.3.19 Q_{ge}—lateral edge heat flow rate between primary Guard and Controlled Environment, *W*.

3.3.20 Q_{gp}—lateral heat flow rate across the gap, *W*.

3.3.21 Q_{grd}—guard heat flow through Specimen, *W*.

3.3.22 Q_{se}—edge heat flow between Specimen and Controlled Environment, *W*.

3.3.23 R—thermal resistance, m^2 K/W.

3.3.24 ΔT—temperature difference across the specimen, $T_h - T_c$.

3.3.25 T_c—cold surface temperature, K.

3.3.26 T_h—hot surface temperature, K.

3.3.27 T_m—mean temperature, K, $(T_h + T_c)/2$.

3.3.27.1 *Discussion*— The Guarded-Hot-Plate Apparatus provides a means for measurement of steady state heat flux through insulation materials, that consists of a guarded heater unit, comprised of a center metering area and concentric separately heated guards, and an opposite, similarly sized cooling plate. Specimens are placed in the space between the heater plate and the cooling plate for testing. The guarded-hot-plate is operated as a single or double sided apparatus. Insulation thermal properties are calculated from measurements of metering area, energy input, temperatures, and thickness. The guarded-hot-plate, which provides an absolute measurement of heat flux, has been shown to be applicable for most insulating materials over a wide range of temperature conditions.

4. Summary of Test Method

4.1 Fig. 1 illustrates the main components of the idealized system: two isothermal cold surface assemblies and a guarded-hot-plate. It is possible that some apparatuses will have more than one guard. The guarded-hot-plate is composed of a metered section thermally isolated from a concentric primary guard by a definite separation or gap. Some apparatus may have more than one guard. The test specimen is sandwiched between these three units as shown in Fig. 1. In the double-sided mode of measurement, the specimen is actually composed of two pieces. The measurement in this case produces a result that is the average of the two pieces and therefore it is important that the two pieces be closely identical. For guidance in the use of the one-sided mode of measurement, the user is directed to Practice C1044. For guidance in the use of a guarded-hot-plate incorporating the use of a line source heater, refer to Practice C1043.

4.1.1 The guarded-hot-plate provides the power (heat flow per unit time) for the measurement and defines the actual test volume, that is, that portion of the specimen that is actually being measured. The function of the primary guard, and additional coplanar guard where applicable, of the guarded-hot-plate apparatus is to provide the proper thermal conditions within the test volume to reduce lateral heat flow within the apparatus. The proper (idealized) conditions are illustrated in Fig. 1 by the configuration of the isothermal surfaces and lines of constant heat flux within the specimen.