Designation: C1043 – 19

Standard Practice for Guarded-Hot-Plate Design Using Circular Line-Heat Sources[1]

This standard is issued under the fixed designation C1043; 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 practice covers the design of a circular line-heat-source guarded hot plate for use in accordance with Test Method C177.

NOTE 1—Test Method C177 describes the guarded-hot-plate apparatus and the application of such equipment for determining thermal transmission properties of flat-slab specimens. In principle, the test method includes apparatus designed with guarded hot plates having either distributed- or line-heat sources.

1.2 The guarded hot plate with circular line-heat sources is a design in which the meter and guard plates are circular plates having a relatively small number of heaters, each embedded along a circular path at a fixed radius. In operation, the heat from each line-heat source flows radially into the plate and is transmitted axially through the test specimens.

1.3 The meter and guard plates are fabricated from a continuous piece of thermally conductive material. The plates are made sufficiently thick that, for typical specimen thermal conductances, the radial and axial temperature variations in the guarded hot plate are quite small. By proper location of the line-heat source(s), the temperature at the edge of the meter plate is made equal to the mean temperature of the meter plate, thus facilitating temperature measurements and thermal guarding.

1.4 The line-heat-source guarded hot plate has been used successfully over a mean temperature range from − 10 to + 65°C, with circular metal plates and a single line-heat source in the meter plate. The chronological development of the design of circular line-heat-source guarded hot plates is given in Refs (**1-9**).[2]

NOTE 2—Detailed drawings and descriptions for the construction of two line-heat-source guarded-hot-plate apparatuses are available in the adjunct.[3]

1.5 This practice does not preclude (*1*) lower or higher temperatures; (*2*) plate geometries other than circular; (*3*) line-heat-source geometries other than circular; (*4*) the use of plates fabricated from ceramics, composites, or other materials; or (*5*) the use of multiple line-heat sources in both the meter and guard plates.

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

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

1.8 *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:*[4]

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

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

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

2.2 *ASTM Adjuncts:*

Line-Heat-Source Guarded-Hot-Plate Apparatus[3]

3. Terminology

3.1 *Definitions*—For definitions of terms and symbols used in this practice, refer to Terminology C168. For definitions of

[1] This practice 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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[2] The boldface numbers in parentheses refer to a list of references at the end of this practice.

[3] Available from ASTM Headquarters. Order Adjunct: ADJC1043.

[4] 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.

terms relating to the guarded-hot-plate apparatus refer to Test Method C177.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *gap, n*—a separation between the meter plate and guard plate, usually filled with a gas or thermal insulation.

3.2.2 *guard plate, n*—the outer ring of the guarded hot plate that encompasses the meter plate and promotes one-dimensional heat flow normal to the meter plate.

3.2.3 *guarded hot plate, n*—an assembly, consisting of a meter plate and a co-planar, concentric guard plate that provides the heat input to the specimens.

3.2.4 *line-heat-source, n*—a thin or fine electrical heating element that provides uniform heat generation per unit length.

3.2.5 *meter area, n*—the mathematical area through which the heat input to the meter plate flows normally under ideal guarding conditions into the meter section of the specimen.

3.2.6 *meter plate, n*—the inner disk of the guarded hot plate that contains one or more line-heat sources embedded in a circular profile and provides the heat input to the meter section of the specimens.

3.2.7 *meter section, n*—the portion of the test specimen through which the heat input to the meter plate flows under ideal guarding conditions.

4. Significance and Use

4.1 This practice describes the design of a guarded hot plate with circular line-heat sources and provides guidance in determining the mean temperature of the meter plate. It provides information and calculation procedures for: (*1*) control of edge heat loss or gain (Annex A1); (*2*) location and installation of line-heat sources (Annex A2); (*3*) design of the gap between the meter and guard plates (Appendix X1); and (*4*) location of heater leads for the meter plate (Appendix X2).

4.2 A circular guarded hot plate with one or more line-heat sources is amenable to mathematical analysis so that the mean surface temperature is calculated from the measured power input and the measured temperature(s) at one or more known locations. Further, a circular plate geometry simplifies the mathematical analysis of errors resulting from heat gains or losses at the edges of the specimens (see Refs **(10, 11)**).

4.3 The line-heat source(s) is (are) placed in the meter plate at a prescribed radius such that the temperature at the outer edge of the meter plate is equal to the mean surface temperature over the meter area. Thus, the determination of the mean temperature of the meter plate is accomplished with a small number of temperature sensors placed near the gap.

4.4 A guarded hot plate with one or more line-heat sources will have a radial temperature variation, with the maximum temperature differences being quite small compared to the average temperature drop across the specimens. Provided guarding is adequate, only the mean surface temperature of the meter plate enters into calculations of thermal transmission properties.

4.5 Care shall be taken to design a circular line-heat-source guarded hot plate so that the electric-current leads to each heater either do not significantly alter the temperature distributions in the meter and guard plates or else affect these temperature distributions in a known way so that appropriate corrections are applied.

4.6 The use of one or a few circular line-heat sources in a guarded hot plate simplifies construction and repair. For room-temperature operation, the plates are typically of one-piece metal construction and thus are easily fabricated to the required thickness and flatness. The design of the gap is also simplified, relative to gap designs for distributed-heat-source hot plates.

4.7 In the single-sided mode of operation (see Practice C1044), the symmetry of the line-heat-source design in the axial direction minimizes errors due to undesired heat flow across the gap.

5. Design of a Guarded Hot Plate with Circular Line-Heat Source(s)

5.1 *General*—The general features of a circular guarded-hot-plate apparatus with line-heat sources are illustrated in Fig. 1. For the double-sided mode of operation, there are two specimens, two cold plates, and a guarded hot plate with a gap between the meter and guard plates. The meter and guard plates are each provided with one (or a few) circular line-heat sources.

5.2 *Summary*—To design the meter and guard plates, use the following suggested procedure: (*1*) establish the specifications and priorities for the design criteria; (*2*) select an appropriate material for the plates; (*3*) determine the dimensions of the plates; (*4*) determine the type, number, and location of the line-heat source(s); (*5*) design the support system for the plates; and (*6*) determine the type, number, and location of the temperature sensors.

5.3 *Design Criteria*—Establish specifications for the following parameters of the guarded hot-plate apparatus: (*1*) specimen diameter; (*2*) range of specimen thicknesses; (*3*) range of specimen thermal conductances; (*4*) characteristics of specimen materials (for example, stiffness, mechanical compliance, density, hardness); (*5*) range of hot-side and cold-side test temperatures; (*6*) orientation of apparatus (vertical or horizontal heat flow); and (*7*) required measurement precision.

NOTE 3—The priority assigned to the design parameters depends on the application. For example, an apparatus for high-temperature will necessitate a different precision specification than that for a room-temperature apparatus.

5.4 *Material*—Select the material for the guarded hot plate by considering the following criteria:

5.4.1 *Ease of Fabrication*—Fabricate the guarded hot plate from a material that has suitable thermal and mechanical properties and which is readily fabricated to the desired shapes and tolerances, as well as facilitate assembly.

5.4.2 *Thermal Stability*—For the intended range of temperature, select a material for the guarded hot plate that is dimensionally stable, resistant to oxidation, and capable of supporting its own weight, the test specimens, and accommodating the applied clamping forces without significant distortion. The coefficient of thermal expansion shall be known in order to calculate the meter area at different temperatures.

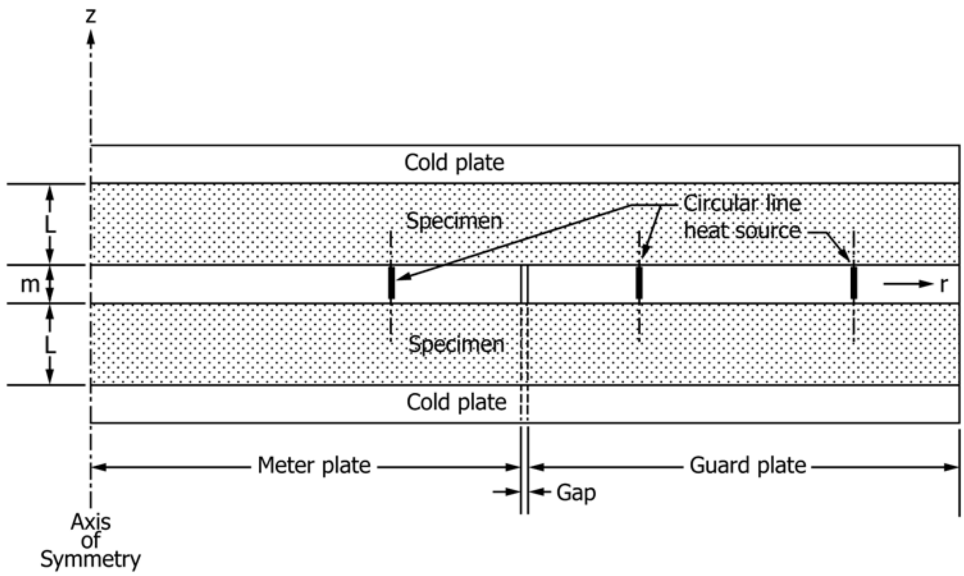

FIG. 1 Schematic of a Line-Heat-Source Guarded-Hot-Plate Apparatus

5.4.3 *Thermal Conductivity*—To reduce the (small) radial temperature variations across the guarded hot plate, select a material having a high thermal conductivity. For cryogenic or modest temperatures, select a metal such as copper, aluminum, silver, gold or nickel. For high-temperature (up to 600 or 700°C) use in air, select nickel or a single-compound ceramic, such as aluminum oxide, aluminum nitride, or cubic boron nitride.

5.4.4 *Heat Capacity*—To achieve thermal equilibrium quickly, select a material having a low volumetric heat capacity (product of density and specific heat). Although aluminum, silver, and gold, for example, have volumetric heat capacities lower than copper, as a practical matter, either copper or aluminum is satisfactory.

5.4.5 *Emittance*—To achieve a uniform, high emittance, select a plate material that will accept a suitable surface treatment. The treatment shall also provide good oxidation resistance. For modest temperatures, various high emittance paints are used for copper, silver, gold, or nickel. For aluminum, a black anodized treatment provides a uniformly high emittance. For high-temperature, most ceramics have an inherently high emittance. Nickel and its alloys form a fairly stable oxide coating at higher temperatures.

5.5 *Guarded-Hot-Plate Dimensions*—Select the geometrical dimensions of the guarded hot plate to provide an accurate determination of the thermal transmission properties.

NOTE 4—The accurate determination of thermal transmission properties requires that the heat input to the meter plate flows normally through the specimens to the cold plates. One-dimensional heat flow is attained by proper selection of the diameter of the meter plate relative to the diameter of the guard plate while also considering (*1*) the specimen thermal conductivities; (*2*) specimen thicknesses; (*3*) edge insulation; and, (*4*) secondary guarding, if any.

5.5.1 *Meter Plate and Guard Plate Diameters*—Use Annex A1 to determine either the diameter of the guard plate for a given meter plate diameter, or the diameter of the meter plate for a given guard plate diameter. Specifically, determine the combinations of diameters of the meter plate and guard plate that will be required so that the edge-heat-loss error will not be excessive for the thickest specimens, with the highest lateral thermal conductances. If necessary, calculate the edge heat loss for different edge insulation and secondary-guarding conditions.

NOTE 5—For example, when testing relatively thin specimens of insulation, maintain the ambient temperature at essentially the mean temperature of the specimens and to use minimal edge insulation without secondary guarding. However, for thicker conductive specimens, edge insulation and secondary guarding are necessary to achieve the desired test accuracy.

5.5.2 *Guarded-Hot-Plate Thickness*—The plate thickness shall provide proper structural rigidity, and have a large lateral thermal conductance, thus minimizing radial temperature variations in the plate. A large thickness, however, will increase the heat capacitance of the plate and thus adversely affect the (rapid) achievement of thermal equilibrium, and reduce the thermal isolation between the meter plate and the guard plate.

5.5.3 *Gap Width*—The gap shall have a uniform width such that the gap area, in the plane of the surface of the guarded hot plate, shall be less than 3 % of the meter area. In any case, the width of the gap shall not exceed the limitations given in Test Method C177. The width of the gap is a compromise between increasing the separation in order to reduce lateral heat flow and distorting the heat flow into the specimen and increasing the uncertainty in the determination of the meter area.

NOTE 6—The gap provides a significant thermal resistance between the meter and guard plates. The temperature difference across the gap shall be maintained at a very small value, thereby minimizing the heat transfer between the meter and guard plates, both directly across the gap and also through adjacent portions of the specimens.

5.5.4 *Gap Configuration*—Refer to Fig. 2 in selecting an appropriate design for the gap cross-section. Designs (*b*) and (*c*) permit a narrow gap at the surfaces, in the plane of the plate, while maintaining a fairly high thermal resistance between the meter and guard plates. For a small temperature difference