Designation: C1044 – 16 (Reapproved 2020)

Standard Practice for Using a Guarded-Hot-Plate Apparatus or Thin-Heater Apparatus in the Single-Sided Mode[1]

This standard is issued under the fixed designation C1044; 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 determination of the steady-state heat flow through the meter section of a specimen when a guarded-hot-plate apparatus or thin-heater apparatus is used in the single-sided mode of operation.

1.2 This practice provides a supplemental procedure for use in conjunction with either Test Method C177 or C1114 for testing a single specimen. This practice is limited to only the single-sided mode of operation, and, in all other particulars, the requirements of either Test Method C177 or C1114 apply.

NOTE 1—Test Methods C177 and C1114 describe the use of the guarded-hot-plate and thin-heater apparatus, respectively, for determining steady-state heat flux and thermal transmission properties of flat-slab specimens. In principle, these methods cover both the double- and single-sided mode of operation, and at present, do not distinguish between the accuracies for the two modes of operation. When appropriate, thermal transmission properties shall be calculated in accordance with Practice C1045.

1.3 This practice requires that the cold plates of the apparatus have independent temperature controls. For the single-sided mode of operation, a (single) specimen is placed between the hot plate and the cold plate. Auxiliary thermal insulation, if needed, is placed between the hot plate and the auxiliary cold plate. The auxiliary cold plate and the hot plate are maintained at the same temperature. The heat flow from the meter plate is assumed to flow only through the specimen, so that the thermal transmission properties correspond only to the specimen.

NOTE 2—The double-sided mode of operation requires similar specimens placed on either side of the hot plate. The cold plates that contact the outer surfaces of these specimens are maintained at the same temperature. The electric power supplied to the meter plate is assumed to result in equal heat flow through the meter section of each specimen, so that the thermal transmission properties correspond to an average for the two specimens.

1.4 This practice does not preclude the use of a guarded-hot-plate apparatus in which the auxiliary cold plate is either larger or smaller in lateral dimensions than either the test specimen or the cold plate.

NOTE 3—Most guarded-hot-plate apparatus are designed for the double-sided mode of operation (**1**).[2] Consequently, the cold plate and the auxiliary cold plate are the same size and the specimen and the auxiliary insulation will have the same lateral dimensions, although the thicknesses need not be the same. Some guarded-hot-plate apparatus, however, are designed specifically for testing only a single specimen that is either larger or smaller in lateral dimensions than the auxiliary insulation or the auxiliary cold plate.

1.5 This practice is suitable for use for both low- and high-temperature conditions.

1.6 This practice shall not be used when operating an apparatus in a double-sided mode of operation with a known and unknown specimen, that is, with the two cold plates at similar temperatures so that the temperature differences across the known and unknown specimens are similar.

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:*[3]

C168 Terminology Relating to Thermal Insulation[3]

C177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus[3]

C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus[3]

C1045 Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions[3]

[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.

Current edition approved Oct. 1, 2020. Published October 2020. Originally approved in 1985. Last previous edition approved in 2016 as C1044 – 16. DOI: 10.1520/C1044-16R20.

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

[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.

C1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminology C168. For definitions of terms relating to the guarded-hot-plate apparatus or thin-heater apparatus refer to Test Methods C177 or C1114, respectively,

3.2 *Definitions of Terms Specific to This Standard:*

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

3.2.2 *auxiliary insulation, n*—thermal insulation used in place of a second test specimen, when the single-sided mode of operation is used (syn. dummy specimen).

3.2.3 *cold plate, n*—the plate that provides an isothermal boundary at the cold surface of the specimen.

3.2.4 *double-sided mode, n*—operation of the apparatus, such that the heat input to the meter plate flows equally through two specimens, each specimen placed on either side of the hot plate (see also **single-sided mode**).

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

3.2.6 *guard plate, n*—the outer (rectangular or circular) ring of the guarded hot plate, that encompasses the meter plate and promotes one-dimensional heat flow normal to the meter plate.

3.2.7 *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 specimen(s).

3.2.8 *meter plate, n*—the inner (rectangular or circular) plate of the guarded hot plate, that provides the heat input to the meter section of the specimen(s).

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

3.2.10 *single-sided mode, n*—operation of the apparatus such that essentially all of the heat input to the meter plate flows through a specimen placed on one side of the hot plate (see also **double-sided mode**).

3.2.11 *thin heater, n*—an assembly, consisting of an unpartitioned thin-screen heater or thin-foil, that provides the heat input to the specimen(s).

3.3 *Symbols*—The symbols used in this practice have the following significance. The prime (') denotes quantities associated with the auxiliary insulation used to control heat from the other side of the hot plate.

3.3.1 A—meter area of hot plate, m^2.

3.3.2 C'—thermal conductance of auxiliary insulation, $W/(m^2 \cdot K)$.

3.3.3 Q—heat flow through meter section of specimen, W.

3.3.4 Q'—heat flow through meter section of auxiliary insulation, W.

3.3.5 Q_m—power input to meter plate, W.

3.3.6 T_c—surface temperature of cold plate, K.

3.3.7 T'_c—surface temperature of auxiliary cold plate, K.

3.3.8 T_h—surface temperature of hot plate in contact with specimen, K.

3.3.9 T'_h—surface temperature of hot plate in contact with auxiliary insulation, K.

4. Significance and Use

4.1 This practice provides a procedure for operating the apparatus so that the heat flow, Q', through the meter section of the auxiliary insulation is small; determining Q'; and, calculating the heat flow, Q, through the meter section of the specimen.

4.2 This practice requires that the apparatus have independent temperature controls in order to operate the cold plate and auxiliary cold plate at different temperatures. In the single-sides mode, the apparatus is operated with the temperature of the auxiliary cold plate maintained at the same temperature of the hot plate face adjacent to the auxiliary insulation.

NOTE 4—In principle, if the temperature difference across the auxiliary insulation is zero and there are no edge heat losses or gains, all of the power input to the meter plate will flow through the specimen. In practice, a small correction is made for heat flow, Q', through the auxiliary insulation.

4.3 The thermal conductance, C', of the auxiliary insulation shall be determined from one or more separate tests using either Test Method C177, C1114, or as indicated in 5.4. Values of C' shall be checked periodically, particularly when the temperature drop across the auxiliary insulation less than 1 % of the temperature drop across the test specimen.

4.4 This practice is used when it is desirable to determine the thermal properties of a single specimen. For example, the thermal properties of a single specimen are used to calibrate a heat-flow-meter apparatus for Test Method C518.

5. Procedure for Single-Sided Mode of Operation

5.1 Refer to Fig. 1 for a schematic diagram of the single-sided mode of operation of the guarded-hot-plate apparatus.

NOTE 5—The schematic diagram for a thin-heater apparatus (not shown) is similar, except the hot plate is much thinner and is not partitioned by a gap.

5.2 Follow the procedure of either Test Method C177 or C1114 with the following modifications.

5.3 Select a rigid or semi-rigid material for the auxiliary insulation having a low thermal conductance so that heat gains or losses from the face of the meter plate in contact with the auxiliary insulation will be small. The thickness and lateral conductance of the auxiliary insulation shall be small to avoid significant effects on the heat transfer through the meter section of the auxiliary insulation due to heat transfer at the edge of the auxiliary insulation.

NOTE 6—The influence of edge effects for a particular apparatus and test configuration is determined experimentally as described in Test Method C177 or by computation using one of the procedures referenced in Test Method C177 or described by Peavy and Rennex (**2**).

5.4 Determine C' of the auxiliary insulation over the temperature range of interest using one of the following procedures: *(1)* Test Method C177 or C1114 in a separate test setup for a matched pair of similar specimens; or *(2)* in-situ as described in Annex A1.

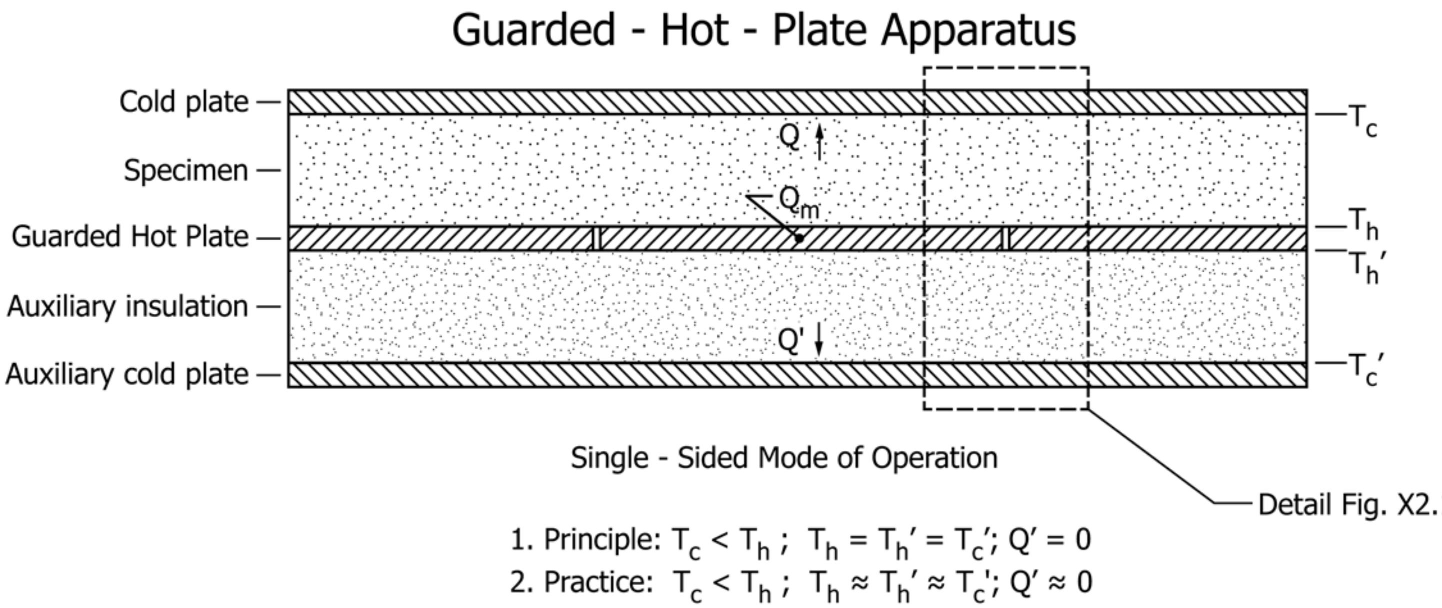

FIG. 1 Diagram Illustrating Single-Sided Mode of Operation of the Guarded-Hot-Plate Apparatus

5.4.1 In the first instance, using either Test Method C177 or C1114, a matched pair of similar specimens is required so that either single specimen subsequently is suitable for use as the auxiliary insulation.

5.4.2 In the second instance using in-situ as described in Annex A1, successive tests are required, one with a small temperature difference across the test specimen and one with a small temperature difference across the auxiliary insulation.

NOTE 7—In 5.4 the user is not required to determine values for *C'* for every test that will be conducted. Rather, determine *C'* as a function of temperature over the temperature range of interest so that a corresponding regression curve is developed for subsequent testing.

5.5 When using a compressible material as the auxiliary insulation, determine *C'* either at the same thickness as that used in the single-sided mode of operation or compressed to (at least) two slightly different thicknesses, thus allowing interpolation for the thickness actually used in the single-sided mode of operation.

5.5.1 For an apparatus without a separate provision for determining the individual thicknesses of the two specimens on opposite sides of the hot plate, place three or more low-conductance rigid spacers near the outer periphery of the guard plate between the hot plate and the surface of the auxiliary cold plate.

5.5.2 Compute the effective thickness of the test specimen by subtracting the thickness of the rigid spacers (corrected for thermal expansion, if necessary) from the thickness that is determined for the test specimen plus the auxiliary insulation. In this case, the separate tests of thermal conductance according to 5.4.2 shall be conducted with rigid spacers.

5.6 Maintain the cold plate at the required temperature T_c. Provide power input to the hot plate to attain the required temperature T_h on the hot side of the test specimen.

5.7 Maintain the temperature T'_c as closely as practical to the temperature T'_h.

5.8 Establish thermal steady-state conditions in accordance with either Test Method C177 or C1114.

5.9 Acquire the required test data and determine A, Q_m, T_h, T'_h, and T'_c in accordance with either Test Method C177 or C1114.

6. Calculation

6.1 Calculate the heat flow through the auxiliary insulation as follows:

$$Q' = C' A \left(T'_h - T'_c\right) \tag{1}$$

where:

C' is the thermal conductance of the auxiliary insulation at a temperature corresponding to $(T'_h + T'_c)/2$, as obtained according to 5.4.

6.2 Calculate the heat flow through the specimen as follows:

$$Q = Q_m - Q' \tag{2}$$

6.3 Use the value of Q, thus obtained to calculate steady-state thermal transmission properties, in accordance with either Test Method C177 or C1114. When appropriate, consult Practice C1045 to calculate steady-state thermal transmission properties. For reference, calculation equations are provided in Appendix X1.

7. Sources of Experimental Error

7.1 Errors in the determination of Q, are introduced from several sources, including measurement of the power input Q_m to the meter plate; estimation of the heat flow, Q', through the auxiliary insulation and, for guarded hot plates, estimation of the heat flow across the gap between the meter plate and guard plate, that is, gap error.

7.2 Refer to either Test Method C177 or C1114 for discussion on the uncertainty in the measurement of the metered-area power (Q_m).

7.3 Estimate the uncertainty ($\Delta Q'$) in Q' by a propagation of error using the terms in Eq 1. Refer to Ku (**3**) for using error propagation formulas.

NOTE 8—When the terms Q_m and Q' in Eq 2 are different by at least two orders of magnitude, a large uncertainty in Q' results in a small uncertainty in Q. For example, suppose that the ratio Q_m/Q' is 100 and suppose that the ratio $\Delta Q'/Q'$ is 0.1. The percentage uncertainty in Q due to $\Delta Q'$, then, would be 0.1 %.

7.4 Refer to Appendix X2 for a discussion of the gap error.

7.5 Refer to Appendix X3 for a discussion on Precision and Bias and Measurement Uncertainty.

8. Report

8.1 Report all measurements in accordance with either Test Method C177 or C1114. Perform all calculations in accordance with Practice C1045. The report shall note that the apparatus was operated in a single-sided mode in accordance with Practice C1044 and, in addition, the report shall include, where applicable, values for quantities associated with the auxiliary insulation, including Q', T'_c and T'_h. The report shall include a description of the apparatus and the procedure for determining C'in 5.4.

9. Keywords

9.1 guarded-hot-plate apparatus; heat flow; single-sided; steady state; thermal insulation; thin-heater apparatus

ANNEX

(Mandatory Information)

A1. IN-SITU DETERMINATION OF THERMAL CONDUCTANCE OF AUXILIARY INSULATION

A1.1 This annex describes an iterative procedure for determining the thermal conductance of the auxiliary insulation from test data acquired with the hot-plate apparatus operated in the single-sided mode.

A1.2 *Procedure*:

A1.2.1 Install the auxiliary insulation and specimen in the apparatus. Conduct the following sequence of tests over the temperature range of interest.

A1.2.2 Following the procedure of Sections 5 and 6, calculate the thermal conductance, C, of the test specimen at a mean temperature corresponding to $(T_h + T_c)/2$. Determine C for at least three values of mean temperature over the temperature range of interest selected in A1.2.1.

A1.2.2.1 For the first iteration, the user shall estimate a value for C' based on experience, handbook data, etc.

A1.2.3 Using the same temperature range selected in A1.2.1, establish a small temperature difference, $T_h - T_c$, for example, <2 K across the specimen and a significant temperature difference, $T'_h - T'_c$, for example, 20 K to 30 K across the auxiliary insulation.

A1.2.4 Calculate the heat flow through the specimen as follows:

$$Q = CA\left(T_h - T_c\right) \quad \text{(A1.1)}$$

where:

C is the thermal conductance of the test specimen at a temperature corresponding to $(T_h + T_c)/2$, as determined in A1.2.2. Interpolation for the value of C will potentially be required.

A1.2.5 Calculate the heat flow through the auxiliary insulation as follows:

$$Q' = Q_m - Q \quad \text{(A1.2)}$$

A1.2.6 Using the value of Q', thus obtained, calculate the thermal conductance of the auxiliary insulation, C', corresponding to a mean temperature of $(T'_h + T'_c)/2$. Determine C' for at least three values of mean temperature.

A1.2.7 Repeat A1.2.2 through A1.2.6 until successive values of C' vary be no more than 1 %.

APPENDIXES

(Nonmandatory Information)

X1. THERMAL TRANSMISSION EQUATIONS

X1.1 For reference, equations for calculating thermal transmission properties are provided in X1.2.

X1.2 *Symbols*—The following symbols refer to equations in Appendix X1.

A = meter area of hot plate, m^2.
Q = heat flow through meter section of test specimen, *W*.
C = thermal conductance of specimen, *W/*(m^2•*K*).
R = thermal resistance of specimen, (m^2•*K*)/*W*.
λ = thermal conductivity of specimen, *W/*(m•*K*)
r = thermal resistivity of specimen, (m•*K*)/*W*
L = specimen thickness, m.
T_c = surface temperature of cold plate, *K*.
T_h = surface temperature of hot plate in contact with test specimen, *K*.

$$C = Q/A(T_h - T_c)) \quad (X1.1)$$

$$R = (A(T_h - T_c))/Q \quad (X1.2)$$

$$\lambda = (LQ)/(A(T_h - T_c)) \quad (X1.3)$$

$$r = (A(T_h - T_c))/(LQ) \quad (X1.4)$$

X2. DISCUSSION OF ERROR DUE TO GAP HEAT FLOW IN A GUARDED-HOT-PLATE APPARATUS

X2.1 An error occurs due to lateral heat flows across the gap when a guarded-hot-plate apparatus designed for operation in a double-sided mode is used in a single-sided mode. This appendix discusses the sources for this error and procedures to estimate its magnitude.

NOTE X2.1—Error resulting from heat flow across the gap due to a temperature imbalance between the meter plate and guard plate is also discussed in Test Method C177.

X2.2 Most guarded hot plates are constructed with a distributed heat source and surface plates of metal on either side of the heater core. When operated in a double-sided mode of operation, the symmetrical construction will result in the surfaces on either side of the meter plate attaining nearly the same temperature; however, when operated in a single-sided mode, the temperature of the side of the meter plate that contacts the auxiliary insulation is significantly hotter than the side that contacts the test specimen.

X2.3 For illustration, Fig. X2.1 shows the heat flows in the region of the gap of a guarded-hot-plate apparatus under conditions when temperature differences are present. Path A represents heat flow through the region of the test specimen that is in close proximity to the gap. Similarly, Path E represents heat flow through the auxiliary specimen. Paths B, C, and D correspond to heat flows across portions of the gap on the test specimen side, in the center, and on the auxiliary specimen side, respectively.

X2.4 The critical requirement for eliminating heat flow across the gap is the proper design of the guarded hot plate and installation of the temperature sensors, such that the net heat flow between the meter and guard plates, integrated over all paths, be zero when the measured temperature difference is, in fact, zero.

X2.5 *Hypothetical Example*:

X2.5.1 Fig. X2.2 shows the cross section, near the gap, of a (hypothetical) guarded hot plate designed for double-sided mode of operation. The meter and guard plates are identical in construction having a symmetrical heater core with (wire or ribbon) heaters electrically insulated from metal surface plates. The two heaters are part of a single winding and cannot be operated separately. The thermopile used to control the temperature of the guard plate, relative to the temperature of the meter plate, has its junctions located in the surface plates (Fig. X2.2a).

NOTE X2.2—Actual designs of guarded hot plates need not be the same as the hypothetical design shown in Fig. X2.2. This simple design was selected to illustrate the differences in temperature profiles that can arise when equipment designed for operation in a double-sided mode is used in a single-sided mode.

X2.5.2 *Double-Sided Mode*—The first temperature profile shown in Fig. X2.2b illustrates the variation in spatially averaged temperature through the guarded hot plate when it is operated in the double-sided mode with identical heat fluxes on each side. The surface plates of metal have a high thermal conductivity and are presumed isothermal. The temperature gradient across the electrical insulating layer between each heater and the corresponding surface plate is due to the heat flow from that heater into the test specimen (not shown) in contact with the surface plate. The region between the heaters, on average, is isothermal since the net heat flow in or out of the region is zero. The temperature drop across each insulating layer, ideally, is proportional to the temperature drop across the test specimen times the ratio of the thermal conductance of the specimen to the insulating layer; thus, if the insulating layer is thin and has a relatively high thermal conductivity, the temperature drop across each insulating layer will be a very small fraction of the temperature drop across the test specimen. If the heat flux to the guard heater is the same as that to the meter heater, that is, there are no significant heat losses from the outer edge of the guard plate, the temperature in the heater core region essentially will be the same for the guard plate as it is for the meter plate. In such a case, controlling the power input to the guard plate so that the gap thermopile gives a null output, not only will result in the temperatures of the surface plates