Designation: C 1044 – 98 (Reapproved 2003)

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

## 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 C 177 or C 1114 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 C 177 or C 1114 apply.

NOTE 1—Test Methods C 177 and C 1114 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 C 1045.

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 essentially the same temperature. Ideally, 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 essentially 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 may be 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 thickness may be different. Some guarded-hot-plate apparatus, however, are designed specifically for testing only a single specimen that may be either larger or smaller in lateral dimensions than that auxiliary insulation or the auxiliary cold plate.

1.5 This practice can be used 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 and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

C 168 Terminology Relating to Thermal Insulation[3]

C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus[3]

C 518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat-Flow Meter Apparatus[3]

C 1045 Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions[3]

C 1114 Test Method for Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus[3]

## 3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminology C 168. For definitions of terms

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[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 Measurements.

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

[3] *Annual Book of ASTM Standards*, Vol 04.06.

relating to the guarded-hot-plate apparatus or thin-heater apparatus refer to Test Methods C 177 or C 1114, 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 a 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 $A$—metre 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, as close as possible, to the temperature of the side of the hot plate adjacent to the auxiliary insulation.

NOTE 4—Ideally, 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 must be determined from one or more separate tests using either Test Method C 177, C 1114, or as indicated in 5.4. The values of $C'$ should be checked periodically, particularly if during regular testing it is not possible to keep the temperature drop across the auxiliary insulation less than 1 % of the temperature drop across the test specimen.

4.4 This practice can be 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 C 518. In other cases, there may be only one specimen available.

## 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) in similar, except the hot plate is much thinner and is not partitioned by a gap.

5.2 Follow the procedure of either Test Method C 177 or C 1114 with the following modifications.

5.3 Select a semi-rigid material for the auxiliary insulation having a low thermal conductance so that heat gains or losses from the back side of the meter plate will be small. The thickness and lateral conductance of the auxiliary insulation should be small enough 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 can be determined experimentally as described in Test Method C 177 or by computation using one of the procedures referenced in Test Method C 177 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. Either Test Method C 177 or C 1114 in a separate test setup for a matched pair of similar specimens, or in-situ as described in Annex A1 will be used.

5.4.1 In the first instance using either Test Method C 177 or C 1114, a match pair of similar specimens is required so that either single specimen subsequently can be used as the auxiliary insulation specimen.

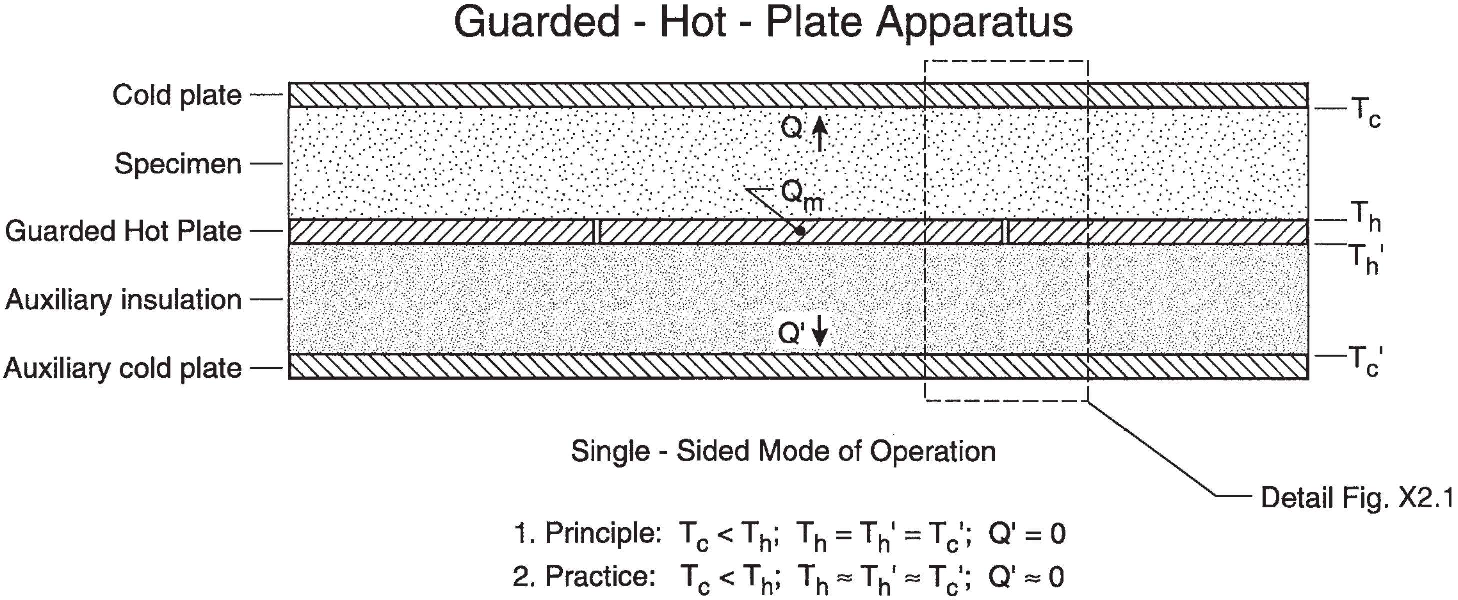

FIG. 1 Diagram Illustrating Single-Sided Mode of Operation of the Guarded-Hot-Plate Apparatus

5.4.2 In the second instance using in-situ as described in Annex A1, pairs of test 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 it is not intended for the user to determine values for $C'$ for every test that is to be conducted. Rather determine $C'$ as a function of temperature over the temperature range of interest so that a corresponding regression curve may be developed and used 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.

5.6 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 (see Test Method C 177). 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 compression also should be conducted with rigid spacers.

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

5.8 Maintain the temperature $T'_c$ of the auxiliary cold plate as closely as practical to the temperature $T'_h$ on the back side of the hot plate.

5.9 Establish thermal steady-state conditions in accordance with either Test Method C 177 or C 1114.

5.10 Acquire the required test data and determine $A$, $Q_m$, $T_h$, $T'_h$, and $T'_c$ in accordance with either Test Method C 177 or C 1114.

## 6. Calculation

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

$$Q' = C' A (T'_h - T'_c) \qquad (1)$$

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:

$$Q = Q_m - Q' \qquad (2)$$

6.3 Use the value of $Q$, thus obtained to calculate steady-state thermal transmission properties, in accordance with either Test Method C 177 or C 1114. When appropriate, consult Practice C 1045 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 $Q$, can be 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 and guard plates, that is, gap error.

7.2 Refer to either Test Method C 177 or C 1114 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—The terms, $Q_m$ and $Q'$ in Eq 2 should be different by at least two orders of magnitude, if possible. Thus, a large uncertainty in $Q'$ may result 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.

## 8. Report

8.1 Report all measurements in accordance with either Test Method C 177 or C 1114. When appropriate perform all calculations in accordance with Practice C 1045. The report should note that the apparatus was operated in a single-sided mode in accordance with Practice C 1044 and should 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.

NOTE A1.1—For the first iteration, the user must 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:

$$Q = CA\,(T_h - T_c) \qquad \text{(A1.1)}$$

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 $C$ may be required.

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

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

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.

$A$ = metre area of hot plate, m$^2$.
$Q$ = heat flow through meter section of test specimen, $W$.
$C$ = thermal conductance of specimen, $W/(\text{m}^2\cdot K)$.
$R$ = thermal resistance of specimen, $(\text{m}^2\cdot K)/W$.
$\lambda$ = thermal conductivity of specimen, $W/(\text{m}\cdot K)$
$r$ = thermal resistivity of specimen, $(\text{m}\cdot K)/W$
$L$ = specimen thickness, m.
$T_c$ = surface temperature of cold plate, $K$.
$T_h$ = surface temperature of hot plate in contact with test specimen, $K$.

$$C = Q/A(T_h - T_c)) \qquad \text{(X1.1)}$$

$$R = (A(T_h - T_c))/Q \qquad \text{(X1.2)}$$

$$\lambda = (LQ)/(A(T_h - T_c)) \qquad \text{(X1.3)}$$

$$r = (A(T_h - T_c))/(LQ) \qquad \text{(X1.4)}$$

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

X2.1 Error may occur due to undesired 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 undesired heat flow across the gap due to a temperature imbalance between the meter and guard plate also is discussed in Test Method C 177.

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 may be 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 assumed 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 may differ markedly from 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. Designs of actual guarded hot plates should be reviewed using this example as a guide to assess what problems they may have in either mode of operation.

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

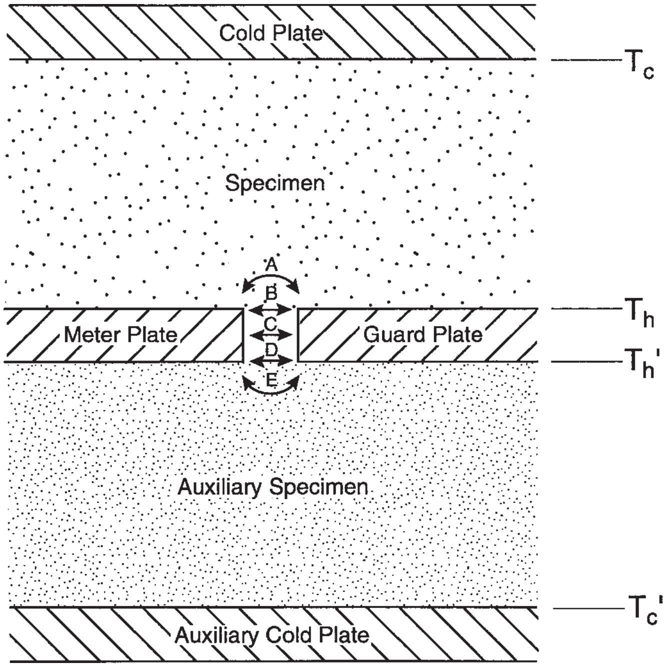

FIG. X2.1 Diagram Illustrating Heat Flows at Gap Region

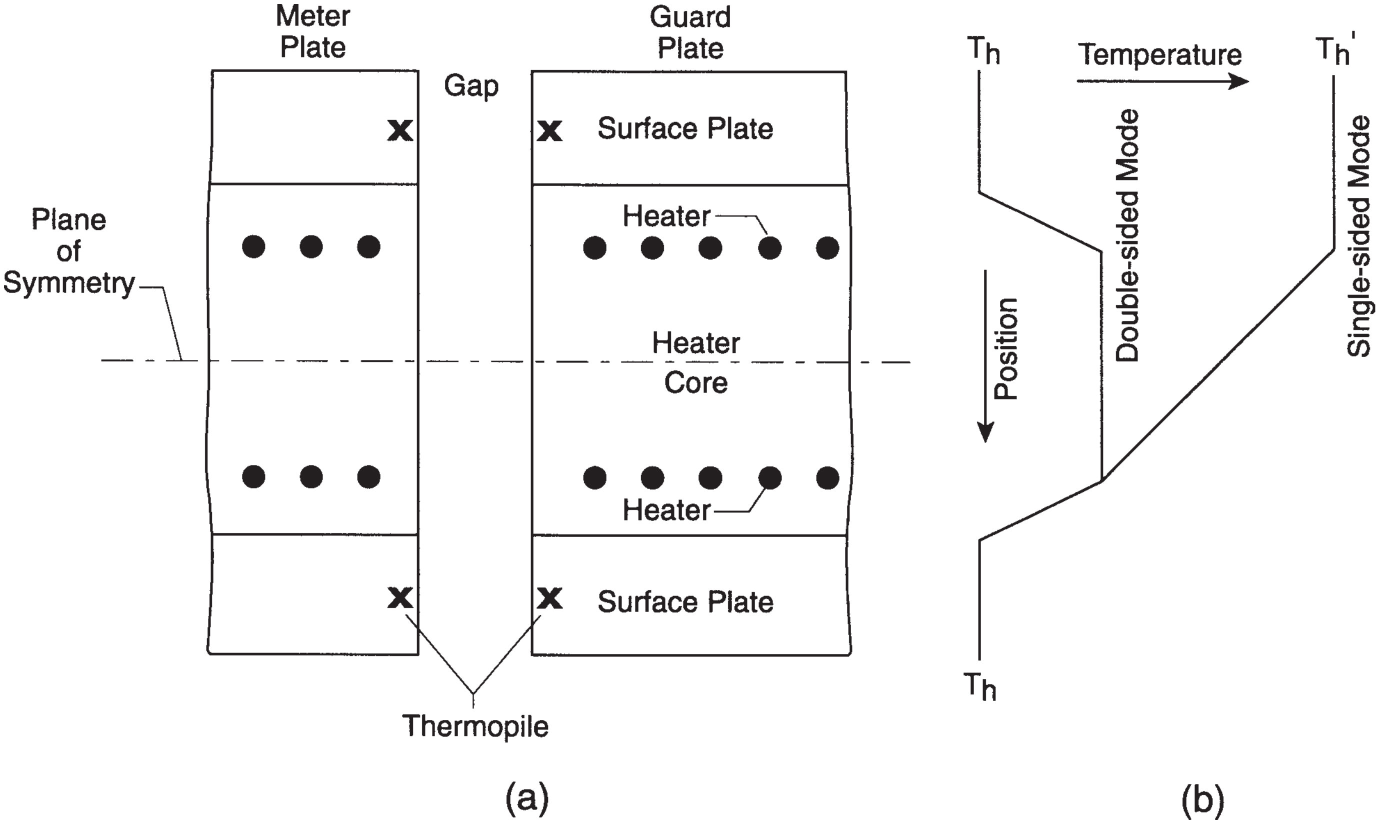

FIG. X2.2 Diagram of (Hypothetical) Guarded-Hot-Plate with Distributed Heat Source, and (b) Corresponding Temperature Profile for Double- and Single-Sided Mode of Operation

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 being identical but also will result in a temperature balance between the meter and guard plates.

X2.5.3 *Single-Sided Mode*—In this example, the two heaters are part of a single winding and cannot be operated separately. When operated in a single-sided mode, half of the heat flow through the test specimen comes from the heater on the front side of the guarded hot plate, half from the backside heater. The second temperature profile shown in Fig. X2.2b illustrates the variation in spatially averaged temperature through the guarded hot plate when operated in the single-sided mode with the same heat flux through the test specimen as above (X2.5.2). The temperature drop across the insulating layer on the front side is the same as it was in the double-sided mode, since the total heat flow through that layer is the same in each case; however, the heat flow from the heater on the backside of the hot plate must pass through the heater core region, resulting in a significant temperature drop. In drawing this curve, it is assumed that the surface temperature of the auxiliary cold plate is the same as the surface temperature of the backside of the guarded hot plate so that there is no heat flow through the auxiliary insulation and no temperature gradient through the insulating layer behind the heater on the backside of the hot plate. In some guarded hot plate designs, the heater core is thick enough, and its thermal conductivity low enough, that the temperature drop, $T_h'$ - $T_h$, across the guarded hot plate is a significant fraction of the temperature drop across the test specimen. Under such conditions, and depending on the thermopile installation, controlling the guard heater so that the thermopile products a null output may not ensure that infact, there is a temperature balance between the meter and guard plates. In this case, significant errors may occur in the determination of the heat flow through the test specimen due to extraneous heat flows across the gap or across the portions of the test specimen or the auxiliary specimen in the proximity of the gap.

X2.6 For a guarded-hot-plate apparatus that can be operated in both the double- and single-sided mode, the significance of errors in the gap heat flow should be determined by conducting measurements on the same specimens in both modes of operation, preferably with the same hot-side and cold-side temperatures in both modes of testing. The average conductance of a matched pair of specimens should be determined by operating the apparatus in the double-sided mode. The average conductance of this pair of specimens also should be determined from data taken on each specimen in the single-sided mode of operation. It is recommended that such measurements be carried out on several thicknesses of each of several materials, representing the ranges of thermal conductances and thermal conductivities of interest.

NOTE X2.3—The temperature variations in the portions of the guarded hot plate near to the gap will depend primarily on the total heat flow required for the test, and hence, on the thermal conductance of the test specimen. For a given specimen thermal conductance, the extraneous heat flows through the portions of the test and auxiliary specimens adjacent to the gap will depend on the thermal conductivities of these specimens; thus, if there is a significant gap error, it probably will depend upon both the thermal conductances and the thermal conductivity of the test specimen.

X2.7 For a guarded-hot-plate apparatus that only can be operated in the single-sided mode, measurements should be conducted on specimens whose thermal conductance is accurately known from measurements made in another guarded hot plate apparatus, or preferably, from a national standards laboratory. Again, it is recommended that such measurements be conducted on several thicknesses of several materials, representing the ranges of thermal conductances and thermal conductivities of interest.

X2.8 The differences between test data obtained using a single-sided mode of operation and the known thermal conductances obtained using a double-sided mode of operation or obtained in another guarded-hot-plate apparatus can be analyzed to determine the magnitude of gap error, and if enough data are available, its dependence upon the thermal conductance and thermal conductivity of the test specimen. If a significant gap error is found, further analysis of the particular guarded-hot-plate design must be carried out in order to predict the error for other specimen conductances and conductivities. If the error is very large or if reliable corrections cannot be made, the design of the gap thermopile, or even of the guarded hot plate itself, must be changed.

## X3. COMMENTARY

X3.1 *Introduction and History of Practice C 1044*:

X3.1.1 This commentary provides the user with the background and history of this practice. It includes a brief discussion on the precision and bias of using either a guarded-hot-plate apparatus or a thin-heater apparatus in the single-sided mode of operation.

X3.1.2 The guarded-hot-plate apparatus and thin-heater apparatus traditionally have been operated in a double-sided mode of operation. The double-sided mode of operation requires similar specimens placed on either side of the hot plate. The two cold plates that contact the outer surfaces of these specimens are maintained at essentially 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.

X3.1.3 For the single-sided mode of operation, a single specimen is placed between the hot plate and the cold plate. Auxiliary thermal insulation is placed between the hot plate and the auxiliary cold plate, that is, the other cold plate. The auxiliary cold plate and the hot plate are maintained at essentially the same temperature, which requires that each cold plate have separate temperature controls. Ideally, 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.

X3.1.4 In recent years, the single-sided practice has obtained favorable acceptance among several laboratories. The practice is employed frequently when only one specimen is available, for example, a loose-fill specimen prepared by pneumatic application. Further, the practice is required for the preparation of calibrated transfer specimens for use with Test Method C 518. The practice also is used for other research proposes, such as checking the homogeneity of stock material or determining the onset of convection in a specimen.

X3.1.5 In 1985, the practice for using the guarded-hot-plate apparatus in the one-sided mode was adopted by ASTM with a minor revision made in 1989. In 1997, this practice was revised extensively with changes in title and scope.

X3.2 *Precision and Bias*:

X3.2.1 Statements on precision and bias for guard-hot-plate apparatus and thin-heater apparatus are covered in Test Methods C 177 and C 1114, respectively. Currently, the statements do not distinguish between double-sided or single-sided operation. The user is directed instead to the theoretical treatment and interlaboratory tests reported below if information on precision and bias is required.

X3.2.2 A theoretical error analysis for a circular guarded-hot-plate apparatus operated in the single sided mode is discussed by Eguchi (**4**).

X3.2.3 *Interlaboratory Tests*—In 1993, an interlaboratory comparison that involved laboratories with guarded hot plate operated in either double- or single-sided operation was published (**5**).

## REFERENCES

(**1**) Pratt, A.W., “Heat Transmission in Low Conductivity Materials,” Chapter 6 in *Thermal Conductivity*, Vol 1, R.P. Tye, Ed., New York, NY: Academic Press Inc; 1969, pp. 338-357.

(**2**) Peavy, B. and Rennex, B.G., “Circular and Square Edge Effects Study for Guarded-Hot-Plate and Heat-Flow-Meter Apparatuses,” *Journal of Thermal Insulation*, Vol 9, April 1986, pp. 254-300.

(**3**) Ku, H.H., “Notes on the Use of Propagation of Error Formulas,” *Journal of Research of the National Bureau of Standards*, Vol 70C, No. 4, October-November 1966.

(**4**) Eguchi, K., “Error Analysis of Measuring Thermal Conductivity by Circular and One Side Heat Flow Type Guarded-Hot-Plate Apparatus,” *ASTM STP 879*, ASTM, 1985, pp. 49-68.

(**5**) Salmon, D., Silberstein, A., and Kumaran, K., “Report on Interlaboratory Comparison of Guarded-Hot-Plate Measurements,” *National Research Council Canada Internal Report No. 653*, December 1993.

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