Designation: D5930 – 17

Standard Test Method for Thermal Conductivity of Plastics by Means of a Transient Line-Source Technique[1]

This standard is issued under the fixed designation D5930; 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 test method covers the determination of the thermal conductivity of plastics over a temperature range from –40 to 400°C. It is possible to measure the thermal conductivity of filled and unfilled thermoplastics, thermosets, and rubbers in the range from 0.08 to 2.0 W/m.K.

1.2 The values stated in SI units shall be regarded as standard.

1.3 *This standard does not purport to address the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish proper safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—There is no known ISO equivalent to this test method.

1.4 *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:*[2]

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

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

C1113 Test Method for Thermal Conductivity of Refractories by Hot Wire (Platinum Resistance Thermometer Technique)

D618 Practice for Conditioning Plastics for Testing

D883 Terminology Relating to Plastics

D2717 Test Method for Thermal Conductivity of Liquids

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods

E1225 Test Method for Thermal Conductivity of Solids Using the Guarded-Comparative-Longitudinal Heat Flow Technique

3. Terminology

3.1 *Definitions*—Terminology used in this standard is in accordance with Terminology D883.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *temperature transient, n*—the temperature rise associated with the perturbation of a system, initially at a uniform temperature. The system does not attain thermal equilibrium during the transient.

3.2.2 *thermal conductivity, n*—the time rate of steady heat flow/unit area through unit thickness of a homogeneous material in a direction perpendicular to the surface induced by a unit temperature difference.

3.2.2.1 *Discussion*—Where other modes of heat transfer are present in addition to conduction, such as convection and radiation, this property often is referred to as the apparent thermal conductivity, λ_{app}.

3.2.2.2 *Discussion*—Thermal conductivity must be associated with the conditions under which it is measured, such as temperature and pressure, as well as the compositional variation of the material. It is possible that thermal conductivity will vary with direction and orientation of the specimen since some materials are not isotropic with respect to thermal conductivity. In the case of thermoset polymers, it is possible that thermal conductivity will vary with the extent of cure.

3.2.3 *thermal diffusivity*—a heat-transport property given by the thermal conductivity divided by the thermal mass, which is a product of the density and the heat capacity.

3.3 *Symbols:*

3.3.1 C—Probe constant.

3.3.2 λ—Thermal conductivity, W/m.K.

3.3.3 Q—Heat output per unit length, W/m.

3.3.4 T_2—The temperature (K) recorded at time t_2.

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.30 on Thermal Properties.

Current edition approved Aug. 1, 2017. Published August 2017. Originally approved in 1997. Last previous edition approved in 2016 as D5930 - 16. DOI: 10.1520/D5930-17.

[2] 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.

*A Summary of Changes section appears at the end of this standard

3.3.5 T_1—The temperature (K) recorded at time t_1.

3.4 *Subscript:*

3.4.1 *av*—average.

3.4.2 *app*—apparent.

3.4.3 *ref*—reference.

4. Summary of Test Method

4.1 *Line-Source Technique*—This is a transient method for determining thermal conductivity (**1, 2**).[3] A line source of heat is located at the center of the specimen being tested. The apparatus is at a constant initial temperature. During the course of the measurement, a known amount of heat produced by the line-source results in a heat wave propagating radially into the specimen. The rate of heat propagation is related to the thermal diffusivity of the polymer. The temperature rise of the line-source varies linearly with the logarithm of time (**3**). It is possible to use this relationship to directly calculate the thermal conductivity of the sample. There are a number of ways to achieve the line source of heat. In this test method, it is in the form of a probe as described in 7.2.

5. Significance and Use

5.1 The relative simplicity of the test method makes it applicable for a wide range of materials (**4, 5**). The technique is capable of fast measurements, making it possible to take data before the materials suffer thermal degradation. Alternatively, it is possible to study the effect of compositional changes such as chemical reaction or aging (**6**). Short measurement times permit generation of large amounts of data with little effort. The line-source probe and the accompanying test specimen are small in size, making it possible to subject the sample to a wide range of test conditions. Because this test method does not contain a numerical precision and bias statement, it shall not be used as a referee test method in case of dispute.

6. Interferences

6.1 The line-source method produces results of highest precision with materials where intimate contact with the probe has been established, thereby eliminating effects of thermal contact resistance. These materials include viscous fluids and soft solids.

6.1.1 *Thermal-Contact Resistance*—In the solid state, it is possible that a contact resistance is developed due to the interface between the specimen and the measuring device. Conventional methods attempt to account for this by introducing a conductive paste between the specimen and the sensor. This reduces, but some effect of contact resistance is still possible. In the line-source method, contact resistance manifests itself as a nonlinearity in the initial portion of the transient (see Fig. 1). The technique has a method to account for this phenomenon. By extending the time of the measurement, it is possible to progress beyond the region of thermal-contact resistance, achieving a state where the contact resistance does not contribute to the measured transient (**7**). This state typically

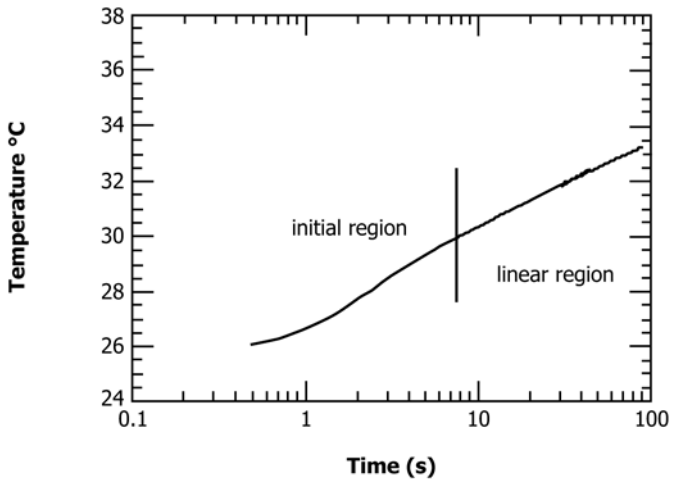

FIG. 1 Line-Source Transient

is achieved after about 10 to 20 s in the measurement. The larger the contact resistance, the greater is this time. It is, therefore, important to make a sufficiently long measurement to exclude the portion of the transient that shows the effect of the contact resistance. The duration of measurement, however, must not be too long, because the possibility of the heat wave striking a sample boundary exists, thereby violating the theoretical requirements of the measurement.

6.1.2 *Shrinkage Upon Solidification*—Plastics tend to shrink significantly upon solidification. This shrinkage is especially so for the semi-crystalline materials, which experience a significant change in specific volume upon crystallization. The probability exists that this crystallization will result in large gaps being developed between the specimen and the sensing device. To account for shrinkage, and possibly permit the line-source probe to move downward to take up the slack a simple compression scheme as described in 9.5 has been used successfully. Steps also must be taken to minimize specimen volume so as to reduce the extent of shrinkage.

6.2 Measurements in viscid fluids are subject to the development of convection currents, which have been known to affect the measurement. Because of the transient nature of the measurement, these effects are not as pronounced. They cannot be eliminated, however.

6.3 Although the technique is not limited by temperature, at measurements above 500°C, a significant amount of heat transfer occurs due to radiation so that it is possible to measure only a λ_{app}.

7. Apparatus

7.1 The apparatus consists of a line-source probe imbedded in a specimen contained in a constant-temperature environment. During the measurement, the line-source probe produces a precise amount of heat. The resulting temperature transient is recorded, preferably, on a computer data-acquisition system, as specified in 7.4. This transient is analyzed to obtain the thermal conductivity.

7.2 *Line-Source Probe*—The line-source probe contains a heater that runs the length of the probe (**3**). The length-to-diameter ratio of the probe must be greater than 20. The

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

resistance of the line-source heater must be known to within ±0.1 %. The probe also contains a temperature sensor to measure the temperature transient. A typical sensor for the line-source probe is a high-sensitivity *J*-type thermocouple used because of its large Seebeck coefficient. The housing sheath of the probe must be robust enough to ensure that the probe does not bend or deform under the adverse conditions it is subject to during measurements.

7.3 *Heater Power Source*—The power input to the line-source heater comes from a DC voltage source. The precision of the voltage source must be within ±0.25 % over the entire duration of the test.

7.4 *Recording Device*—The temperature transient from the line-source probe is recorded for the duration of the test. A temperature measurement device with a resolution of 0.1°C is required. Data are acquired for 30 to 120 s depending on the type of material. Typical temperature rises are between 2 and 10°C over the duration of the measurement. The frequency of data acquisition must be at least once every second.

7.5 *Specimen Environment*—A constant-temperature environment must be maintained through the duration of the test so as to provide a temperature stability in the specimen of within ±0.1°C. Failure to attain this criterion will on occasions compromise the linearity of the transient, thereby affecting the test result. The environment shall be free from excessive vibration.

7.5.1 *Ambient*—For measurements close to ambient temperature, use of a stirred water bath is one method to be used to maintain the test temperature. Alternatively, placing the specimen, adequately shielded to protect it from convection, is a possible alternative.

7.5.2 *Cryogenic Temperatures*—Placing a specimen adequately shielded from convection in a controlled cryogenic bath or chamber is acceptable.

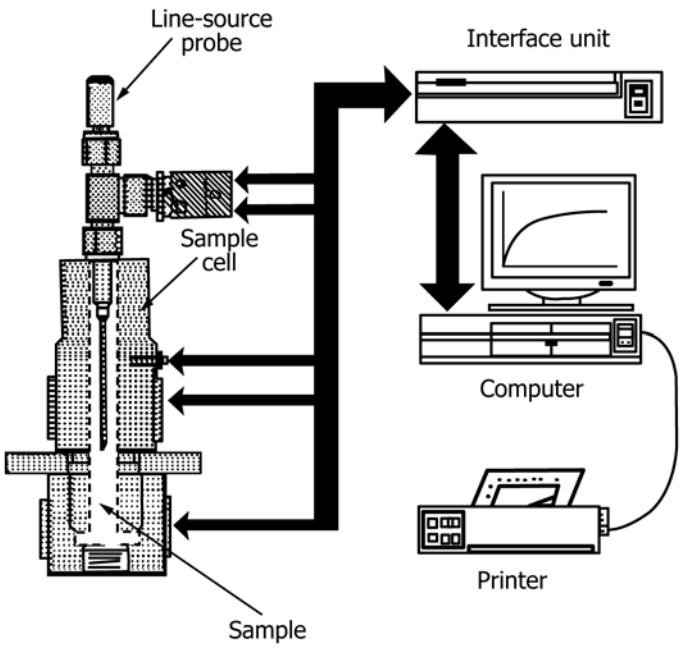

FIG. 2 Adaptation for Measurements at Elevated Temperatures

7.5.3 *Elevated Temperatures*—At temperatures above ambient, a special heated cell is required. This consists of a vertical cylindrical heated chamber, fitted with a removable plug at the bottom. The specimen is loaded from the top and is discharged through the bottom, once the test is complete (see Fig. 2).

8. Conditioning

8.1 Many thermoplastic materials must be dried because moisture has been shown to affect the properties. Moisture causes molten polymer samples to foam, which will affect the measured thermal conductivity. Conditioning is generally not a requirement of this test; if conditioning is necessary, see the applicable material specification or Practice D618.

9. Preparation of Test Specimen

9.1 The test specimen prepared from plastic pellets, liquids, foams, or soft solids is acceptable. The specimen-preparation method depends on the type of material being tested. If the material is believed to be anisotropic, at least three specimens must be tested. Specimens must be longer than the line-source probe and large enough in radius to have at least 4 mm of material surrounding the probe, so that the expanding heat wave will not strike a boundary during the measurement.

9.2 *Viscous Liquids*—These include pastes and semisolids. Pour or extrude the specimen into a test tube or similar cylindrical container. The container must be filled with sufficient quantity of fluid such that the probe is immersed completely.

9.3 *Soft Solids*—Insert the line-source probe directly into the specimen, taking care to see that it does not bend during insertion. A specimen of any size or shape as long as it is larger than the minimum specified in 9.1 is acceptable. In the case where the specimen cannot be penetrated without being destroyed, it is permissible to drill a pilot hole that is smaller than the probe diameter to aid in insertion.

9.4 *Thermoplastics in the Melt*—Preheat the sample cell to the lowest melt processing temperature of the thermoplastic. Loading specimens at a low temperature is desirable to ensure an air-free specimen. Pour a charge of the specimen, typically in pellet or powder form, into the cell and compress into a homogeneous mass. Several charges, tamped well, are often needed to fill the sample cell. When the specimen is well molten, insert the probe so as to be near the axial center of the specimen. Sealing systems are sometimes employed to contain the specimen. For thermally unstable materials, follow material manufacturers' recommendations on temperature exposure limits.

9.5 *Solid Thermoplastics*—Load the sample in the same manner as in 9.4. The following precautionary steps are needed to account for shrinkage of the specimen as it solidifies. The probe shall be fitted with a dynamic sealing system permitting it to move with the shrinking specimen. Static loads placed on the probe to help maintain contact as the plastic shrinks are acceptable and recommended. These loads optimally will apply a pressure of 1 to 7 MPa on the specimen.

9.6 *Thermosets and Rubber*—Preheat the sample cell to a loading temperature, above the glass transition, where the specimen is fluid enough to be molded but will not undergo significant reaction (**6**). If the sample cell is to be reused, wipe the walls of the cell with a thin layer of a release agent such as silicone oil to prevent the cured specimen from bonding to the cell. Charge or pour the uncured specimen in the same manner as in 9.4. For best results, do not coat the probe with release agents since this might affect the test results.

10. Calibration

10.1 The actual probe and sample cell differ in many ways from the theoretical situation, which assumes an infinitely long probe in an infinite specimen. Judicious design of the probe and sample cell will often minimize some of the non-idealities. Practical limitations in probe construction, however, are such that a calibration is necessary to account for such effects as the thermal mass of the probe and the fact that the precise length of the line-source cannot be determined. A probe constant must be obtained by calibrating the probe against a material of known thermal conductivity. The constant depends on the probe characteristics and has no significant temperature sensitivity. The ideal value of the probe constant is 1.0. Typical values range from 0.8 to 0.9.

10.2 *Reference Material*—An ideal reference material is a well-characterized, viscous liquid. Such a system will not be subject to thermal contact resistance effects. Because of the high viscosity, convection effects are not present. A polydimethylsiloxane fluid[4] is in common use as a reference material. This material has a thermal conductivity of 0.16 W/m.K at room temperature (**8, 9**).

10.3 *Probe Calibration*—In the equations in 12.2, the probe constant is set to 1.0. The line-source probe is immersed in the reference material of known thermal conductivity λ_{ref}, which is at the reference temperature. At least five measurements must be performed as outlined in Section 11. The resulting values of thermal conductivity are calculated based on 12.2, for each case and the results averaged yielding λ_{av}.

$$C = \lambda_{ref}/\lambda_{av} \tag{1}$$

It is recommended that calibration be verified at least once a month.

11. Procedure

11.1 Before beginning experiments, examine the line-source probe. The probe must be straight and its surface free of residues, oil, or water. Nonresidue solvents and copper gauze are recommended for cleaning. The sample cell must be clean and free of residues.

11.2 Prepare the specimen and insert the probe as applicable for the appropriate sample type, as described in Section 9. Ensure that the probe is secure and the system is not subject to any form of vibration or temperature fluctuation.

11.3 In general, low power outputs are desirable to prevent excessive perturbation of the system. The amount of power input to the line-source heater is dependent on the characteristics of the material being tested. A high-thermal-diffusivity material dissipates heat at a faster rate so that a larger amount of heat is needed. Conversely, low-thermal-diffusivity materials, such as foams and insulations require a small amount of heat input.

11.4 Allow the system to attain temperature stability, as defined in the criteria in 7.5. Supply the heat input to the line-source. Simultaneously, record the temperature and time for the duration of the measurement.

11.5 It is acceptable to make multiple measurements if desired at these same conditions, provided that the system is permitted to stabilize prior to each measurement.

11.6 Change the sample environment conditions for the next measurement. Continue the process until the desired range of test conditions have been covered. Where a change of physical state occurs over the range of conditions tested, acquire at least two measurements in each state.

11.7 Clean up the system by extracting the probe under the same conditions as those under which it was loaded. The only exception to this rule is in the case of thermosets where the specimen has solidified around the probe. Cutting rubbers away from the probe using a sharp razor has been found to be successful. It is possible to remove rigid thermosets by thermal decomposition using a Bunsen burner. This procedure must be performed with adequate fume removal. The probe temperature must be monitored so that it does not exceed permissible limits. Remove all adhering materials. Do not scratch, mar, or bend the probe during cleaning.

11.8 Inspect the specimen for voids. If specimen has been subjected to conditions where it might have undergone degradation, note and report such evidence.

12. Calculation

12.1 Plot the temperature rise against log time. Obtain the slope of the linear portion of the curve. Neglect initial nonlinearities, which occur because of the heat wave propagating through the walls of the probe and also due to contact resistance, where the phenomenon exists (**7**).

12.2 Perform the calculations using the following equation:

$$\lambda = \frac{C\,Q^1}{4\pi\,Slope} \tag{2}$$

where:

$$Slope = \frac{T_2 - T_1}{ln(t_2/t_1)}\,K \tag{3}$$

12.3 *Test Conditions*—The temperature at which the thermal conductivity is to be reported is the equilibrium temperature of the specimen prior to the start of the measurement, reported to the nearest whole number. If the time of the measurement is to be recorded, report the time at the start of the measurement. Report any other conditions that are unique to the measurement.

13. Report

13.1 Report the following information:

13.1.1 Description of the material and test specimen.

[4] Polydimethylsiloxane, trimethylsiloxyteminated, 60,000 CS, from Huls America, Bristol, PA 19007.

13.1.2 Description of the apparatus.

13.1.3 Reference material used for calibration including its thermal conductivity value.

13.1.4 Details of the probe, including probe constant, length, and power output.

13.1.5 Thermal conductivity at the relevant test conditions, such as temperature or time.

13.2 Report if the specimen has undergone any physical or chemical change during testing.

14. Precision and Bias

14.1 Table 1 is based on a repeatability study involving a single laboratory. The materials used were unfilled polypropylene and polycarbonate resins. Measurements were performed by a single technician on a single day. Each test result is an individual determination. Five measurements were obtained for each material.

14.2 Attempts to develop a full precision and bias statement for this test method have not been successful. Because this test method does not contain round-robin based precision data, it shall not be used as a referee test method in case of dispute. It is requested that anyone wishing to participate in the development of precision and bias data should contact the Chairman, Subcommittee D20.30 (Section D20.30.07), ASTM, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428–2959.

TABLE 1 Repeatability Data for Thermal Conductivity (W/m·K) of Polypropylene and Polycarbonate

Material	Test Temperature, °C	Average	S_r[A]	r[B]
Polypropylene	200	0.164	0.0019	0.0053
Polycarbonate	280	0.263	0.0058	0.0162

[A] S_r = within-laboratory standard deviation of the average.
[B] r = within-laboratory repeatability limit = 2.8 × S_r.

14.3 There are no recognized standards on which to base an estimate of bias for this test method.

15. Keywords

15.1 line-source probe; line-source technique; plastics; rubber; thermal conductivity; thermoplastics; thermosets

REFERENCES

(1) Hooper, F. C., and Lepper, F. R.,Trans. Am. Soc. Heat. Vent. Engrs., Vol 56, 1950, p. 309.
(2) Eustachio, D., and Schreiner, R. E., Trans. Am. Soc. Heat. Vent. Engrs., Vol 58, 1952, p. 331.
(3) Lobo, H., and Cohen, C., Polym. Eng. Sci., Vol 30, 1990, p. 65.
(4) Haugh, C. H., and Sweat, V. E., Trans. ASAE, Vol 56, 1974.
(5) McTaggart, R. B., and Underwood, W. M., "Heat Transfer (Storrs)," Chem. Eng. Prog. Sym. Series, Vol 56, No. 30, 1960, p. 261.
(6) Lobo, H., *SPE Technical Papers*, Vol XXXVIII, 1991, p. 1281.
(7) Tye, R. P., ed., "Thermal Conductivity," Vol 2, p. 377.
(8) Bates, O. K., Ind. Eng. Chem., Vol 41, No. 9 , 1949, p. 1966.
(9) "Silicon Compounds Register and Review," Petrarch Systems, Inc., 1984, p. 190.