Standard Test Method for
Thermal Conductivity of Liquids[1]

1. Scope

1.1 This test method covers the determination of the thermal conductivity of nonmetallic liquids. It is applicable to liquids that are: (*1*) chemically compatible with borosilicate glass and platinum; (*2*) moderately transparent or absorbent to infrared radiation; and (*3*) have a vapor pressure less than 200 torr at the temperature of test.

1.1.1 Materials that have vapor pressures of up to 345 kPa (50 psia), absolute can be tested provided that adequate measures are taken to repress volatilization of the sample by pressurizing the thermal conductivity cell. The usual safety precautions for pressure vessels shall be followed under these circumstances.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *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:*[2]

D86 Test Method for Distillation of Petroleum Products at Atmospheric Pressure

D1160 Test Method for Distillation of Petroleum Products at Reduced Pressure

D2887 Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography

D2893 Test Methods for Oxidation Characteristics of Extreme-Pressure Lubrication Oils

3. Terminology

3.1 *Units:*

TABLE 1 Selected Conversion Factors for Thermal Conductivity

To Convert From	To	Multiply By
cal/s·cm·°C	w/cm·°C	4.184
cal/s·cm·°C	kcal/h·m·°C	360
cal/s·cm·°C	Btu·in./h·ft²·°F	2903
w/cm·°C	cal/s·cm·°C	0.2389
w/cm·°C	kcal/h·m·°C	86.00
w/cm·°C	Btu·in./h·ft²·°F	693.7
kcal/h·m·°C	cal/s·cm·°C	0.002778
kcal/h·m·°C	W/cm·°C	0.01163
kcal/h·m·°C	Btu·in./h·ft²·°F	8.064
Btu·in./h·ft²·°F	cal/s·cm·°C	0.0003445
Btu·in./h·ft²·°F	W/cm·°C	0.001442
Btu·in./h·ft²·°F	kcal/h·m·°C	0.1240

3.1.1 The energy units used in this test method are defined as follows:

1 Cal (International Table calorie) = 4.1868 absolute J

1 Btu (British thermal unit) = 1055.07 absolute J

3.1.2 The units of thermal conductivity commonly used and their interconversion factors are shown in Table 1.

3.2 For working purposes in this test method, the rounded-off value of 4.19 J/cal is used, as this is adequate for the precision of the test and also represents the rounded-off value of watt-second per calorie units in Table 1, thus avoiding the difficulty caused by the dual definition of the calorie.

3.3 *Symbols:*

T_f = filament temperature, °C,
T_b = bath thermostat temperature, °C,
ΔT = $T_f - T_b$, °C,
r_f = filament radius, cm,
r_i = internal radius of tube, cm,
r_o = external radius of tube, cm,
L = effective length of tube, cm,
R = resistance of filament, Ω,
I = electric current through filament, A,
K_L = thermal conductivity of liquid, cal/s·cm·°C,
K_G = thermal conductivity of glass-tube, cal/s·cm·°C,
A = $[\ln(r_i/r_f)]/2\pi L$, cm^{-1}, and
B = $[\ln(r_o/r_i)]/2\pi L K_G$, s·°C/cal.

4. Summary of Test Method

4.1 A thermal conductivity cell consisting of a straight, four-lead, platinum resistance thermometer element located concentrically in a long, small-diameter, precision-bore borosilicate glass tube is calibrated by accurate measurement of the

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cell dimensions and by determination of the temperature-resistance properties of the platinum element.

4.2 Thermal conductivity is determined by measurement of the temperature gradient produced across the liquid sample by a known amount of energy introduced into the cell by electrically heating the platinum element.

5. Significance and Use

5.1 The thermal conductivity of a substance is a measure of the ability of that substance to transfer energy as heat in the absence of mass transport phenomena. It is used in engineering calculations that relate to the manner in which a given system can react to thermal stresses.

6. Apparatus

6.1 *Thermal Conductivity Cell*, consists essentially of a thin, straight platinum filament sealed axially in a borosilicate glass tube. The filament is held taut by a platinum spring. Two heavy gage platinum studs support the filament at either end and permit the filament itself to serve as the element and a four-lead platinum resistance thermometer. Details and cell construction are shown in Fig. 1.

6.1.1 A tube of 5.00 ± 0.01 mm inside diameter shall be used for liquids of low viscosity as these may create thermal convection problems in the 10.47-mm tube.

6.2 *Temperature Conditioning Bath*, capable of maintaining temperature in the vicinity of the thermal conductivity cell constant and uniform to within ±0.001°C at the test temperature.

6.3 *Resistance Measuring Device*, capable of measuring up to 50 Ω with a sensitivity of at least 10^{-4}Ω. A Mueller bridge assembly with commutator for 4-lead resistance thermometer service or digital multimeter with equivalent sensitivity and a minimum of six digit resistance resolution with 4-lead measurement capability are acceptable.

6.4 *Potential Measuring Device*, capable of measuring up to 1 V with a precision of 10^{-6} V or a potentiometer assembly with sensitivity of at least 1 µV or a digital multimeter with equivalent sensitivity, range, and a minimum of six digit resolution is acceptable.

6.5 *Resistor*, 1-Ω, precision type, with accuracy of ±0.0005 % and stability of ±0.001 % per year.[3,4]

6.6 *Platinum Resistance Thermometer* 4-lead long stem with quartz sheath.
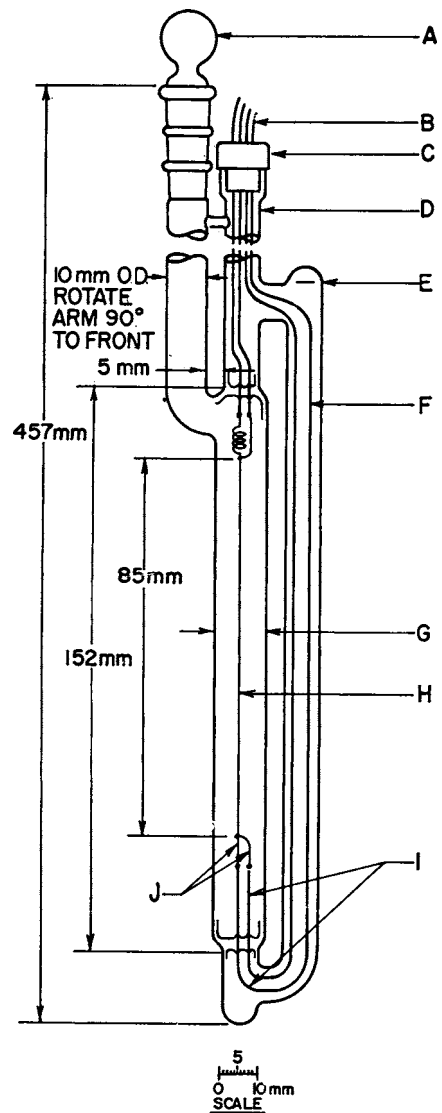
6.7 *Power Supply*, 24-V dc.

NOTE 1—Two 12-V automobile batteries in series have proved satisfactory as a power supply. They should be relatively new and fully charged.

6.8 *Power Supply*, constant-voltage, for potentiometer.[4,5]

A. Penny Head Stopper standard taper 10/30.
B. Gold leads to extend 24 in. beyond PTFE plug. Leads from top and bottom contacts to be of equal length. Excess from top leads to be located in side tube rather than in the top extension of the cell.
C. PTFE plug drilled for wires.
D. 9-mm OD borosilicate glass.
E. Fill top and side tubes with 350 to 500-cSt silicon oil to this level.
F. Insulate gold wire in top and side tubes with woven glass.
G. 10.744 ± 0.0127 mm ID precision bore borosilicate glass tubing.
H. 0.0584-mm dia platinum wire.
I. Use 0.502 mm platinum through glass but add 0.502 mm gold for long leads.
J. 0.203-mm diameter platinum.

FIG. 1 Details of Thermal Conductivity Cell

6.9 *Standard Cell*, unsaturated cadmium type, for potentiometer.[4,6]

6.10 *Switches*, low thermal emf, knife or rotary.

[3] The sole source of supply of Model 9330/1 known to the committee at this time is Guildline Instruments, Inc., 103 Commerce St., Ste. 160, P. O. Box 952590, Lake Mary, FL 32795-2590.
[4] If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.
[5] The sole source of supply of No. 245G-NW-19 known to the committee at this time is Instrulab, Inc., Dayton, OH.
[6] The sole source of supply of a cell of this type known to the committee at this time is Epply Laboratory, Inc., Newport, RI.

TABLE 2 Thermal Conductivity of Dimethyl Phthalate[A]

Temperature, °C	Thermal Conductivity, mW/cm·°C[B]
0	1.501
10	1.491
20	1.480
30	1.468
40	1.456
50	1.443
60	1.430
70	1.417
80	1.403
90	1.389
100	1.373
120	1.343
140	1.310
160	1.273
180	1.236
200	1.199

[A] From combined study by Physikalish Technische Bundesanstalt (Braunschweig, GDR), the Explosives Research and Development Establishment (Waltham Abbey, England) and Mani and Venart (6th Symposium Thermophysical Properties, ASME, 1973, p. 1–14).

[B] The correlation equation for the tabulated data is: $\lambda = 1.5012 - 1.05394 \times 10^{-3}t - 2.23 \times 10^{-6}t^2$, (3)

where:

λ = the thermal conductivity, mW/cm·°C, and
t = the temperature, °C.

6.11 *Silicone Oil*, dimethyl, viscosity at 25°C of 350 to 500 mm²/s (500 cSt).

7. Standardization of Apparatus

7.1 The thermal conductivity of the cell contents, K_L, shall be expressed in terms of the following equation:

$$(\Delta T/I^2R) \times 4.19 = (A/K_L) + B \qquad (1)$$

where *A* and *B* are essentially constants that depend on the dimensions of the cell and its materials of construction. If the cell is purchased the values of these constants should be certified by the manufacturer.

NOTE 2—*A*, in fact, is a constant depending only upon cell geometry, type of glass and, to a lesser extent, the operation of the temperature bath and bath fluid. Within the present recommended accuracy of the method, *B* can be considered to be a constant.

7.2 To determine the absolute values of the cell constants, the various dimensions of the cell are obtained by appropriate measurements made during and after the construction of the cell. The conductivity of the glass cell body is obtained from the manufacturer's literature.

7.3 An additional relative calibration procedure may be used, with reliable thermal conductivity standards. A standard material, such as dimethyl phthalate (Table 2), is placed in the cell. For a given current, ΔT and the cell resistance are measured in the manner described in 8.1. By substituting *B*, as determined in 7.1, and the above-measured values into Eq 1, constant *A* can be determined with accuracy. Small errors in *B* have little effect on the calculated thermalconductivity. Hence, if exact dimensions for the calculation of the value of *B* are not available, a rough approximation will suffice in many instances.

7.4 The temperature-resistance relationship of the cell filament is determined by measurement of its resistance at various

TABLE 3 Thermal Conductivity of Water[A]

Temperature, °C	Thermal Conductivity, J/s·cm °C
25	610.7×10^{-5}
50	644.2×10^{-5}
75	666.3×10^{-5}

[A] Jamieson, D. T. and Tudhope, J. S., "A Simple Device for Measuring the Thermal Conductivity of Liquids with Moderate Accuracy," *Journal of the Institute of Petroleum, JIPEA*, Vol 50, 1964, pp. 150–153.

temperatures with the cell filled with a fluid of high thermal conductivity, such as water (Table 3). To eliminate the effects of self-heating during this calibration, the apparent resistance at each temperature selected is measured at several low bridge currents. The actual resistance is then obtained by extrapolation of the curve of apparent resistance versus current to zero current.

8. Procedure

8.1 Fill the cell with the sample until the liquid reaches a level of about 1 or 2 cm in the sidearm. Place it in the thermostated bath and allow to stand until thermal equilibrium is obtained. Determine equilibrium when the zero-current resistance of the cell reaches a constant value. Apply a higher (up to 30 mA) current to the cell and bridge circuit. Measure the magnitude of this current by monitoring the voltage drop across a 1-Ω resistor in series with the bridge. When the cell again reaches temperature equilibrium as determined by measurement of its filament resistance, measure the bath temperature accurately with a platinum resistance thermometer and take a final reading of cell resistance. Repeat this process at least three times for varying bridge currents. The results will usually show a trend with time at first. Continue measurements until the results are seen to be fluctuating about a mean. Take the final resistance measurements as the mean of readings taken with normal and reverse commutator settings in order that recorded resistances are the resistance of only the active portion of the cell filament and that the effects of the cell leads shall be cancelled. Calculate the temperature difference ΔT as the temperature difference between the cell wire temperature, determined from the cell resistance, and the temperature of the bath.

9. Calculations and Report

9.1 Calculate the thermal conductivity of the sample using Eq 2, used in conjunction with appropriate values of *A* and *B*, as follows:

$$K_L = A/[(4.19\Delta T/I^2R) - B] \qquad (2)$$

9.2 Calculate a preliminary value of K_L using each set of experimental data collected in the manner described above. Average the last three such values to obtain the final value. The reported test temperature shall be the arithmetic mean of the bath temperature and the wire temperature determined from the cell resistance.

NOTE 3—When cgs units are used, the units of K_L are cal/s·cm·°C. The conversion factors in Table 1 can be used to calculate units in other commonly used systems. The use of cgs units followed by conversion of the units K_L as required is recommended as a matter of convenience only as they permit the easy performance of the various calculations involved

in the approximate solution of the Callendar equation for conversion of resistance thermometer readings to actual temperatures.

Note 4—When testing a liquid at a temperature less than 90 % of its absolute 50 % boiling point at one atmosphere, as measured by Test Methods D86, D1160, D2887, D2893, the thermal conductivity data may be expected to be a nearly linear function of temperature. Specifically, if changes in the function $\Delta\lambda/\Delta T$ over two successive ranges of 100°C differ by more than 40 %, the operator should consider recalibration of the apparatus.

10. Precision and Bias

10.1 Because of the complex nature of the procedure for the determination of thermal conductivity and because of the expensive equipment involved in the initial set-up of the procedure, there is not a sufficient number of volunteers to permit a cooperative laboratory program for determining the precision and bias of the method. If the necessary volunteers can be obtained, a program will be undertaken at a later date. As a preliminary estimate, repeatability appears to be about 10 % of the mean of two results by the same operator.

11. Keywords

11.1 nonmetallic liquids; thermal conductivity