Designation: D7896 – 14

Standard Test Method for Thermal Conductivity, Thermal Diffusivity and Volumetric Heat Capacity of Engine Coolants and Related Fluids by Transient Hot Wire Liquid Thermal Conductivity Method[1]

This standard is issued under the fixed designation D7896; 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 use of a transient hot wire liquid thermal conductivity method and associated equipment (the System) for the determination of thermal conductivity, thermal diffusivity and volumetric heat capacity of aqueous engine coolants, non-aqueous engine coolants, and related fluids. The System is intended for use in a laboratory.

1.2 The System directly measures thermal conductivity and thermal diffusivity without the requirement to input any additional properties. Volumetric heat capacity is calculated by dividing the thermal conductivity by the thermal diffusivity of the sample measured.

1.3 This test method can be applied to any aqueous or non-aqueous engine coolants or related fluid with thermal conductivity in the range of 0.1 to 1.0 W/m·K.

1.4 This test method excludes fluids that react with platinum.

1.5 The range of temperatures applicable to this test method is –20 to 100°C.

1.6 This test method requires a sample of approximately 40 mL.

1.7 The System may be used without external pressurization for any fluid having a vapor pressure of 33.8 kPa (4.9 psia) or less at the test temperature.

1.8 For a fluid having a vapor pressure greater than 33.8 kPa (4.9 psia) at the test temperature, external pressurization is required (see Annex A2).

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

1.9.1 *Exception*—Inch-pound units are provided in 1.7, 1.8, 4.1, 7.8, and A2.1 for information.

1.10 *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]

D1176 Practice for Sampling and Preparing Aqueous Solutions of Engine Coolants or Antirusts for Testing Purposes

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions of Thermal Related Units:*

3.1.1 *density* (ρ), *n*—the mass per unit volume of a substance under specific conditions of pressure and temperature. Unit: kg/m^3.

3.1.2 *specific heat capacity* (Cp), *n*—the amount of heat required to raise the temperature of a unit mass of material by 1°C. See Annex A1. Unit: J/(kg·K).

3.1.3 *thermal conductivity* (λ), *n*—rate of heat flow under steady conditions through unit area, per unit temperature gradient in the direction perpendicular to the area. Unit: W/m·K.

3.1.4 *thermal diffusivity* (α), *n*—a measure of the ability of a substance to transmit a difference in temperature. Unit: m^2/s.

3.1.5 *volumetric heat capacity* (VHC), *n*—the amount of heat required to raise the temperature of a unit volume of material by 1°C. Volumetric heat capacity is the thermal conductivity of a material divided by its thermal diffusivity. Unit: $J/m^3 \cdot K$.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *transient hot wire method, n*—a method for measurement of thermal properties wherein a thin wire is immersed in

[1] This test method is under the jurisdiction of ASTM Committee D15 on Engine Coolants and Related Fluids, and is the direct responsibility of Subcommittee D15.22 on Non-Aqueous Coolants.

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[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.

Shown are the controller connected to the platinum-wire sensor with the sensor residing in the sampling cell, along with the liquid specimen. For non-ambient temperature readings, the sampling cell inserts into a temperature control peripheral (not shown). The computer downloads data from the controller for storage and for the creation of spreadsheets and reports.

FIG. 1 Transient Hot Wire Liquid Thermal Conductivity Apparatus

a liquid specimen that is contained in a sampling cell. An instant of current is sent through the wire, heating both the wire and specimen. Immediately afterward, the resistance of the wire is measured with respect to time, while the wire cools. A temperature-time profile of the specimen is produced and from this profile, thermal properties are determined.

3.2.1.1 *dry bath, n*—a temperature control peripheral with a central heating well that receives the sampling cell containing the liquid specimen for providing temperatures above ambient.

3.2.1.2 *heat exchanger and circulator, n*—a temperature control peripheral consisting of a refrigerated/heated circulator for heating and cooling that is connected to a heat exchanger. The heat exchanger has a central well that receives the sampling cell containing the liquid specimen, for providing temperatures above and below ambient.

3.2.1.3 *liquid, n*—refers to the engine coolant or related fluid sample.

4. Summary of Test Method

4.1 A fluid to be tested is placed inside the sampling cell assembly that is part of the System apparatus. The temperature within the sampling cell assembly is regulated by the use of a temperature control peripheral. Regardless of the test temperature, the sample and the System sensor are allowed to equilibrate to approximately the same temperature. The sampling cell assembly may be pressurized by up to a gauge pressure of 241 kPa (35 psig). The sensor, a thin platinum wire, is immersed in the liquid test sample. A current is introduced into the wire over the short test time of 0.8 s that heats both the wire and the liquid sample. The temperature of the wire and the resistance of the wire decay rapidly once the current is removed. The resistance of the wire is measured with respect to time and a temperature versus time profile for the liquid sample is created. From the temperature versus time profile, the thermal conductivity and thermal diffusivity of the liquid specimen are determined. Volumetric heat capacity is determined by dividing the measured thermal conductivity by the measured thermal diffusivity of the specimen.

5. Significance and Use

5.1 This test method covers the measurement of thermal properties for engine coolants (aqueous or non-aqueous) and related fluids.

5.2 With each single measurement, the thermal conductivity (λ) and thermal diffusivity (α) are measured directly, and volumetric heat capacity (VHC) is determined by the relationship:

$$\text{VHC} = \lambda/\alpha \tag{1}$$

5.3 The test method is transient and requires only a small amount of specimen and a short duration of time (0.8 s) to run a measurement. These attributes minimize heat convection in the liquid.

5.4 The brief application of current to the sensor wire adds very little heat to the test specimen and ten repetitive tests may be applied at 30-s intervals without causing any significant convection or temperature drift.

6. Apparatus

6.1 *Transient Hotwire Liquid Thermal Conductivity Measurement System:*

NOTE 1—The descriptions and instructions contained herein are based upon familiarity with the ThermTest, Inc. THW Lambda Transient Hot Wire Liquid Thermal Conductivity Meter.[3] Other equivalent systems may be suitable for this application.

6.1.1 The apparatus for the test method (Fig. 1) consists of a sampling cell assembly with platinum wire sensor inserted, and a controller containing a microprocessor. Unless the measurements are to be made at ambient temperature, the apparatus also includes a temperature control peripheral (either a dry bath or heat exchanger and circulator type). In a typical implementation of the System, a personal computer is used for convenience and greater flexibility in operation, and software supplied by the manufacturer provides the user interface, control of test sequencing, data acquisition, and options for

[3] http://www.thermtest.com.

working with test results in a spreadsheet program. Specific operating instructions are provided in the equipment manuals.

6.2 *Transient Hot Wire Sampling Cell Assembly:*

6.2.1 Fig. 2 shows details of the sampling cell assembly. Fig. 3 shows what the hot wire sensor actually looks like.

7. Specimen and Test Preparations

7.1 The sampling cell must be clean and dry before the liquid to be tested is introduced into it.

7.2 If the liquid to be tested is aqueous and dilutions are required, follow the procedures of Practice D1176 for proper sample preparation.

7.3 If the liquid to be tested is non-aqueous, the liquid specimen is tested directly, without any changes or dilutions. Shake or stir the liquid to assure that it is homogeneous.

7.4 If the liquid to be tested is non-aqueous, it should be assumed to be hygroscopic and its exposure to ambient air should be as brief as possible.

7.5 Introduce approximately 40 mL of sample into the sampling cell. **Important**—make sure that the liquid level is 3 to 4 mL below the threads that are clearly marked on the inner wall of the sampling cell. This allows room for possible thermal expansion of the specimen while heating without any spillage or overflow, yet ensures full immersion of the sensor.

7.6 With the sample introduced, lower the sensor into the sampling cell. Remove any trapped air bubbles near the interface of the sensor and specimen. Air bubbles can introduce errors and significantly degrade the resulting thermal properties measurement. Tap the sampling cell to dislodge any air bubbles, and then screw the sensor onto the sampling cell.

7.7 Refer to Annex A2 to determine if pressure needs to be added to the sampling cell. If pressure is required, follow the manufacturer's instructions with regard to the introduction of pressurization gases.

7.8 Pressure of up to 241 kPa (35 psig) psi may be applied to the sampling cell assembly. An inert gas (from an argon or nitrogen tank) is introduced into the sampling cell assembly through a pressure regulator. The level of pressure introduced is manually controlled and set to the desired level for the measurement. (**Warning—**Use care when applying pressure to the cell, and ensure the proper regulator is used for the intended pressure range and type of inert gas to be used. See the operating manual supplied with the equipment for more information on applying pressure to the sampling cell.)

8. Procedure

8.1 An ambient temperature measurement should be made prior to proceeding with actual sample measurements. Once complete, the controller is balanced and ready for use.

8.2 When testing at other than ambient temperature, follow the instructions in the operating manual provided with the temperature control equipment.

8.3 Perform ten repetitive measurements of the thermal properties of the test specimen:

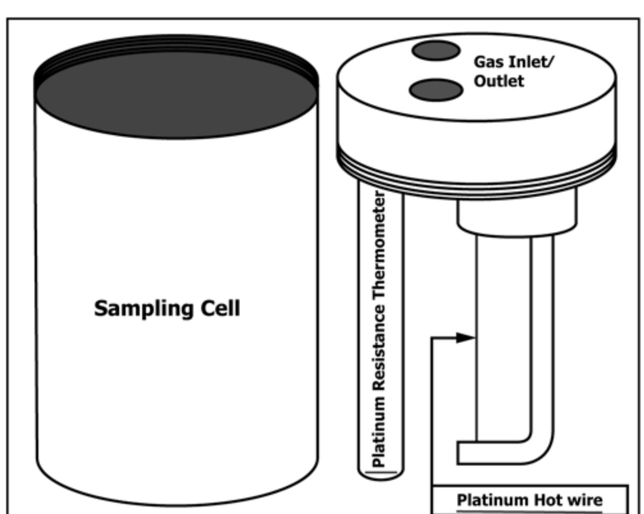
8.3.1 Set the measurement temperature and specify ten thermal property measurements to be made at that temperature.

8.3.2 When the measurement temperature is reached, ten measurements will be automatically performed at 30-s intervals. The results will be displayed on the computer monitor and can be stored according to the System software.

8.4 Refer to the System's operating manual for further instructions on equipment settings, taking and storing measurements, and exporting data files to spreadsheet software.

9. Report

9.1 The report of the results of each test shall include the following information with all data to be reported in SI units unless otherwise specified.



The sampling cell holds the liquid sample and receives the hot wire sensor. The platinum resistance thermometer continuously measures the specimen temperature. The platinum hot wire and the system electronics measure the thermal conductivity and thermal diffusivity of the specimen.

FIG. 2 Sampling Cell Assembly

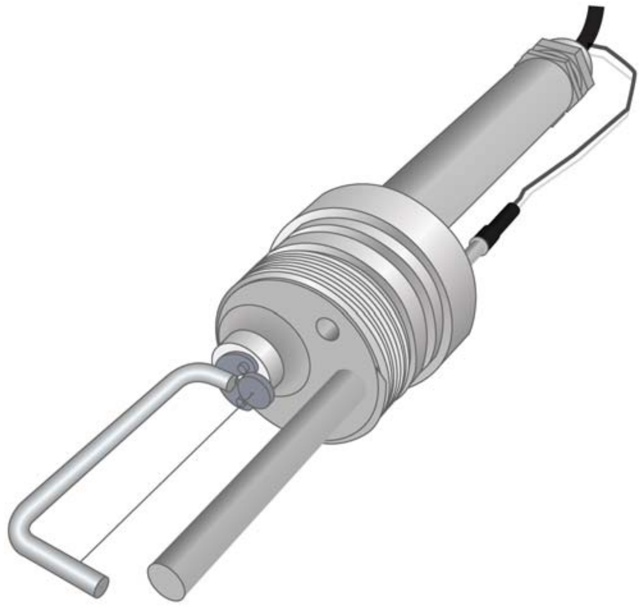


FIG. 3 Close-Up of the Transient Hot Wire Sensor

9.1.1 Date (mo./day/year) and time that each specimen measurement in the report was made.

9.1.2 Temperature of each specimen test, °C.

9.1.3 Thermal conductivity, W/m·K.

9.1.4 The average of the ten thermal conductivity test iterations, W/m·K.

9.1.5 Thermal diffusivity, m^2/s [report as $10^6 \times m^2/s$].

9.1.6 The average of the ten thermal diffusivity test iterations, m^2/s [report as $10^6 \times m^2/s$].

9.1.7 Volumetric heat capacity, $J/m^3 \cdot K$, computed as: (thermal conductivity) / (thermal diffusivity) [report as $kJ/m^3 \cdot K$].

9.1.8 The average of the ten volumetric heat capacity calculations, $J/m^3 \cdot K$ [report as $kJ/m^3 \cdot K$].

10. Precision and Bias[4]

10.1 The precision of this test method is based on an interlaboratory study that was conducted in 2013. A single laboratory participated in this study, testing five liquids for thermal conductivity, thermal diffusivity and volumetric heat capacity. Every "test result" represents an individual determination. The laboratory reported ten replicate test results for each liquid, 150 results total. Except for the use of only one laboratory, Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report No. RR:D15-1034.

10.1.1 *Repeatability (r)*—The difference between repetitive results obtained by the same operator in a given laboratory applying the same test method with the same transient hot wire thermal conductivity measurement system under constant operating conditions on identical test material within short intervals of time would, in the long run, in the normal and correct operation of the test method, exceed the repeatability limits (r) shown in Tables 1-3 only in one case in 20.

10.1.2 Reproducibility limits cannot be calculated from a single laboratory's results.

10.1.3 Any judgment in accordance with statement 10.1.1 would normally have an approximate 95 % probability of being correct, however the precision statistics obtained in this ILS must not be treated as exact mathematical quantities which are applicable to all circumstances and uses. The limited number of laboratories reporting replicate results essentially guarantees that there will be times when differences greater than predicted by the ILS results will arise, sometimes with considerably greater or smaller frequency than the 95 % probability limit would imply. Consider the repeatability limit as a general guide, and the associated probability of 95 % as only a rough indicator of what can be expected.

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D15-1034. Contact ASTM Customer Service at service@astm.org.

TABLE 1 Thermal Conductivity (W/m·K)

	Average $\bar{x}$	Repeatability Standard Deviation s_r	Repeatability Limit r
Dow Syltherm XLT at 40°C	0.106890	0.000970	0.002716
2-Butoxy Ethanol at 60°C	0.152080	0.000225	0.000630
Glycerin at 20°C	0.310690	0.000538	0.001508
50 % Ethylene Glycol/50 % Water (by mass) at 20°C	0.384980	0.001976	0.005534
Ethylene Glycol at 90°C	0.270430	0.000048	0.000135

TABLE 2 Thermal Diffusivity ($10^6 \times m^2/s$)

	Average $\bar{x}$	Repeatability Standard Deviation s_r	Repeatability Limit r
Dow Syltherm XLT at 40°C	0.08072	0.00009	0.00025
2-Butoxy Ethanol at 60°C	0.08183	0.00002	0.00006
Glycerin at 20°C	0.10446	0.00007	0.00020
50 % Ethylene Glycol/50 % Water (by mass) at 20°C	0.11329	0.00025	0.00070
Ethylene Glycol at 90°C	0.08807	0.00000	0.00001

TABLE 3 Volumetric Heat Capacity ($kJ/m^3 \cdot K$)

	Average $\bar{x}$	Repeatability Standard Deviation s_r	Repeatability Limit r
Dow Syltherm XLT at 40°C	1324.420	10.475	29.330
2-Butoxy Ethanol at 60°C	1858.530	2.223	6.225
Glycerin at 20°C	2974.270	3.555	9.953
50 % Ethylene Glycol/50 % Water (by mass) at 20°C	3397.340	10.009	28.025
Ethylene Glycol at 90°C	3070.480	0.352	0.986

10.2 *Bias*—At the time of the study, there was no accepted reference material suitable for determining the bias for this test method. Therefore, no statement on bias is being made.

11. Keywords

11.1 anhydrous; aqueous engine coolants; heat transfer fluids; non-aqueous engine coolants; specific heat capacity; thermal conductivity; thermal diffusivity; volumetric heat capacity; waterless

ANNEXES

(Mandatory Information)

A1. SPECIFIC HEAT CAPACITY

A1.1 The specific heat capacity of the specimen can be calculated by dividing the volumetric heat capacity by the density at the test temperature.

$$Cp = VHC/\rho \tag{A1.1}$$

where:

C_p = specific heat capacity
VHC = volumetric heat capacity
ρ = density

A2. VAPOR PRESSURE CONSIDERATIONS

A2.1 The absolute pressure within the test chamber must be at least three times the vapor pressure of the test sample at the test temperature. For example, water has a vapor pressure of 101.4 kPa (14.7 psia) at 100°C. To study water at 100°C would require an absolute pressure of at least 304.2 kPa (44.1 psia), or a gauge pressure of at least 202.9 kPa (29.4 psig). Non-aqueous engine coolants, in general, have low vapor pressures and in most cases, do not require pressurization at test temperatures of 100°C or less.

A3. CALIBRATION

A3.1 The System is factory-calibrated prior to shipment and it can be recalibrated at any time. A new calibration would be required, for example, if the platinum hot wire of the sensor were broken and a new wire installed.

A3.2 Calibration involves the selection of a well-known and characterized liquid (a suggestion is distilled or deionized water) and running a calibration sequence on the apparatus.

A3.3 Before starting a new calibration, ensure the following conditions are met: thermal conductivity of your reference liquid is known for the temperature at which you are calibrating; the new platinum hot wire is entirely submerged in the reference liquid; the reference liquid is isothermal and the thermal property values on the controller are stable.

A3.4 When the System is recalibrated, the original calibration is stored and can be restored at any time.

A3.5 Refer to the manufacturer's instructions for further information regarding calibration of the system.