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An American National Standard

Standard Test Method for Measuring Apparent Viscosity at High-Temperature and High-Shear Rate by Multicell Capillary Viscometer[1]

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INTRODUCTION

Several different configurations of capillary viscometers have been successfully used for measuring the viscosity of engine oils at the high shear rates and high temperatures that occur in engines. See Test Method D 4624. This test method covers the use of a single apparatus[2] at a single temperature and single shear rate to achieve greater uniformity and improved precision.

1. Scope

1.1 This test method covers the laboratory determination of high-temperature high-shear (HTHS) viscosity of engine oils at a temperature of 150°C using a multicell capillary viscometer containing pressure, temperature, and timing instrumentation. The shear rate for this test method corresponds to an apparent shear rate at the wall of 1.4 million reciprocal seconds (1.4×10^6 s^{-1}).[3] This shear rate has been found to decrease the discrepancy between this test method and other high-temperature high-shear test methods[3] used for engine oil specifications. Viscosities are determined directly from calibrations that have been established with Newtonian oils with viscosities from 2 to 5 mPa·s at 150°C.

1.2 *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:*

D 4624 Test Method for Measuring Apparent Viscosity by Capillary Viscometer at High Shear Rate and High Temperature[4]

D 4683 Test Method for Measuring Viscosity at High Shear Rate and High Temperature by Tapered Bearing Simulator[5]

D 4741 Test Method for Measuring Viscosity at High Temperature and High Shear Rate by Tapered Plug Viscometer[5]

3. Terminology

3.1 *Definitions:*

3.1.1 *apparent shear rate at the wall*—shear rate at the wall of the capillary calculated for a Newtonian fluid, as follows:

$$S_a = 4V/\pi R^3 t \tag{1}$$

where:

S_a = apparent shear rate at the wall, s^{-1},
V = volume, mm^3,
R = capillary radius, mm, and
t = measured flow time, s.

3.1.1.1 *Discussion*—The actual shear rate at the wall will differ for a non-Newtonian fluid.

3.1.2 *apparent viscosity*—the determined viscosity obtained by this test method.

3.1.3 *density*—mass per unit volume.

3.1.3.1 *Discussion*—In the SI, the unit of density is the kilogram per metre cubed (kg/m^3); the gram per cubic centimetre (g/cm^3) is often used. One kg/m^3 is 10^{-3} g/cm^3.

3.1.4 *kinematic viscosity*—the ratio of the viscosity to the density of the fluid.

3.1.4.1 *Discussion*—Kinematic viscosity is a measure of a fluid's resistance to flow under the force of gravity. In the SI, the unit of kinematic viscosity is the metre squared per second (m^2/s); for practical use, a submultiple (millimetre squared per second, mm^2/s) is more convenient. The centistoke (cSt) is 1 mm^2/s and is often used.

3.1.5 *Newtonian oil or fluid*—an oil or fluid that exhibits a constant viscosity at all shear rates or shear stresses.

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[1] This test method is under the jurisdiction of ASTM Committee D-2 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.07.0B on High Temperature Rheology of Non-Newtonian Fluids.

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[2] Manning, R. E., and Lloyd, W. A., "Multicell High Temperature High-Shear Capillary Viscometer," SAE Paper 861562. Available from Society of Automotive Engineers, 400 Commonwealth Dr., Warrendale, PA 15096.

[3] Girshick, F., "Non-Newtonian Fluid Dynamics in High Temperature High Shear Capillary Viscometers," SAE Paper 922288. Available from Society of Automotive Engineers, 400 Commonwealth Dr., Warrendale, PA 15096.

[4] *Annual Book of ASTM Standards*, Vol 05.02.

[5] *Annual Book of ASTM Standards*, Vol 05.03.

3.1.6 *non-Newtonian oil or fluid*—an oil or fluid that exhibits a viscosity that varies with changing shear rate or shear stress.

3.1.7 *shear rate*—the spatial gradient of velocity in laminar flow; the derivative of velocity with respect to distance in a direction perpendicular to the direction of flow.

3.1.7.1 *Discussion*—The derived unit of shear rate is velocity divided by length. With the time in seconds and with consistent units of length, shear rate becomes reciprocal seconds, or s^{-1}.

3.1.8 *shear stress*—force per area of fluid in the direction of flow.

3.1.8.1 *Discussion*—In a capillary viscometer, the significant shear stress is the shear stress at the wall, that is, the total force acting on the cross section of the capillary divided by the area of the inside surface of the capillary. The shear stress at the wall does not depend on the fluid properties (that is, Newtonian or non-Newtonian). The SI unit for shear stress is the pascal (Pa). Mathematically, the shear stress at the wall of a capillary viscometer is as follows:

$$Z = \mathbf{PR/2L} \quad (2)$$

where:

Z = shear stress, Pa,
P = pressure drop, Pa,
R = capillary radius, and
L = capillary length in consistent units.

3.1.9 *viscosity*—the ratio between shear stress and shear rate at the same location.

3.1.9.1 *Discussion*—Viscosity is sometimes called the coefficient of viscosity, or the dynamic viscosity. It is a measure of a fluid's resistance to flow. In the SI, the unit of viscosity is a pascal second (Pa·s); for practical use a submultiple (millipascal second, mPa·s) is more convenient. The centipoise (cP) is 1 mPa·s and is often used.

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *calibrations oils*—those oils used for establishing the instrument's reference framework of apparent viscosity versus pressure drop from which the apparent viscosities of the test oils are determined.

3.2.1.1 *Discussion*—Calibration oils, which are Newtonian fluids, are available commercially[6] or can be blended by the user.

3.2.2 *test oil*—any oil for which the apparent viscosity is to be determined by the test method.

3.2.3 *viscometric cell*—that part of the viscometer comprising all parts which may be wet by the test sample, including exit tube, working capillary, fill tube, pressure/exhaust connection, plug valve, and fill reservoir.

4. Summary of Test Method

4.1 The viscosity of the test oil in any of the viscometric cells is obtained by determining the pressure required to achieve a flow rate corresponding to an apparent shear rate at the wall of 1.4×10^6 s^{-1}. The calibration of each cell is used to determine the viscosity corresponding to the measured pressure.

4.2 Each viscometric cell is calibrated by establishing the relationship between pressure and flow rate for a series of Newtonian oils of known viscosity.

5. Significance and Use

5.1 Viscosity is an important property of fluid lubricants. The viscosity of all fluids varies with temperature. Many common petroleum lubricants are non-Newtonian: their viscosity also varies with shear rate. The usefulness of the viscosity of lubricants is greatest when the viscosity is measured at or near the conditions of shear rate and temperature that the lubricants will experience in service.

5.2 The conditions of shear rate and temperature of this test method are thought to be representative of those in the bearing of automotive engines in severe service.

5.3 Many equipment manufacturers and lubricant specifications require a minimum high-temperature high-shear viscosity at 150°C and 10^6 s^{-1}. The shear rate in capillary viscometers varies across the radius of the capillary. The apparent shear rate at the wall for this test method is increased to compensate for the variable shear rate.[3]

5.4 This test was evaluated in an ASTM cooperative program.[7]

6. Apparatus

6.1 *High-Temperature High-Shear (HTHS) Viscomete*,[8] consisting of several viscometer cells in a temperature-controlled block and including means for controlling and measuring temperature and applied pressure and for timing the flow of a predetermined volume of test oil. Each viscometric cell contains a precision glass capillary and means for adjusting the test oil volume to the predetermined value.

6.1.1 The HTHS viscometer has the following typical dimensions and specifications:

Diameter of capillary	0.15 mm
Length of capillary	15 to 18 mm
Temperature control	150 ± 0.1°C
Pressure range	350 to 3500 KPa (50 to 500 psi)
Pressure control	±1 %
Sample volume	7 ± 1 mL

6.1.2 The thermometer for measuring the temperature of the block is a pre-set digital resistance thermometer. The accuracy of this thermometer may be checked by means of a special thermowell and calibrated thermometer[7] whose accuracy is ±0.1°C or better. See manufacturer's recommendations for procedure.

7. Reagents and Materials

7.1 *Newtonian Oils*,[7] having certified viscosities of 2 to 7 mPa·s at 150°C. See Table 1.

7.2 *Non-Newtonian Reference Sample*,[7] having a certified viscosity at 150°C and 10^6 s^{-1}.

7.3 *Carbon Dioxide or Nitrogen Cylinder*, with reducer valve having a maximum pressure of at least 500 psi (3500 Pa).

[6] Calibration oils, suitable for this purpose, are available from Cannon Instrument Co., P. O. Box 16, State College, PA 16804.

[7] Report is available from ASTM Headquarters. Request RR:D02-1378.

[8] A source of supply is Cannon Instrument Co., P.O. Box 16, State College, PA 16804.