Designation: D5481 – 21

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

This standard is issued under the fixed designation D5481; 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.

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. 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 ($1.4 \times 10^6\ s^{-1}$).[3] This shear rate has been found to decrease the discrepancy between this test method and other high-temperature high-shear test methods[3] (Test Methods D4683 and D4741) used for engine oil specifications. Viscosities are determined directly from calibrations that have been established with Newtonian oils with nominal viscosities from 1.4 mPa·s to 5.0 mPa·s at 150 °C. The precision has only been determined for the viscosity range 1.45 mPa·s and 5.05 mPa·s at 150 °C for the materials listed in the precision section.

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

1.2.1 The centiPoise (cP) is a non-SI metric unit of viscosity that is numerically equal to the milliPascal-second (mPa·s).

1.2.2 Pounds per square inch (psi) is a non-SI unit of pressure that is approximately equal to 6.895 kPa. These units are provided for information only in 6.1.1, 7.3, 9.1.2.1, and the tables.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

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:*[4]

D4683 Test Method for Measuring Viscosity of New and Used Engine Oils at High Shear Rate and High Temperature by Tapered Bearing Simulator Viscometer at 150 °C

D4741 Test Method for Measuring Viscosity at High Temperature and High Shear Rate by Tapered-Plug Viscometer

D6300 Practice for Determination of Precision and Bias Data for Use in Test Methods for Petroleum Products, Liquid Fuels, and Lubricants

D6708 Practice for Statistical Assessment and Improvement of Expected Agreement Between Two Test Methods that Purport to Measure the Same Property of a Material

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.07 on Flow Properties.

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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 (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, www.sae-.org.

[3] Girshick, F., "Non-Newtonian Fluid Dynamics in High Temperature High Shear Capillary Viscometers," SAE Paper 922288. Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, www.sae.org.

[4] 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. Terminology

3.1 *Definitions:*

3.1.1 *apparent viscosity, n*—viscosity of a non-Newtonian liquid determined by this test method at a particular shear rate and shear stress.

3.1.2 *density, n*—mass per unit volume.

3.1.3 *kinematic viscosity, n*—-the ratio of the dynamic viscosity (η) to the density (ρ) of a liquid at a given temperature.

3.1.3.1 *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.

3.1.4 *Newtonian oil, n*—an oil or fluid that at a given temperature exhibits a constant viscosity at all shear rates or shear stresses.

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

3.1.6 *shear rate, n*—velocity gradient perpendicular to the direction of flow.

3.1.6.1 *Discussion*—The velocity gradient in the Multi-Cell Capillary Viscometer varies across the capillary annulus from a maximum at the wall of the capillary to zero at the center of the capillary annulus. Assuming a parabolic flow profile across the capillary, the apparent shear rate at the capillary wall can be calculated as follows:

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

where:

S_a = apparent shear rate (at the wall, s^{-1}),
V = volume of fluid (mm^3) passed through the capillary in time t (s), and
R = capillary radius (mm).

S_a is precise for Newtonian liquids which generate a parabolic flow profile but may be approximate for non-Newtonian liquids that do not necessarily generate a parabolic flow profile.

3.1.7 *shear stress, n*—the force per unit area in the direction of the flow.

3.1.7.1 *Discussion*—In a capillary viscometer, the significant shear stress is at the wall of the capillary. That is, the total force acting on the area of the capillary annulus divided by the inside area of the capillary through which the liquid flows. The shear stress at the wall does not depend on the nature of the liquid (that is, whether the liquid is Newtonian or non-Newtonian). The shear stress at the capillary wall may be calculated as follows:

$$Z = PR/2L \tag{2}$$

where:

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

3.1.8 *viscosity, n*—ratio of applied shear stress and the resulting rate of shear.

3.1.8.1 *Discussion*—It is sometimes called dynamic or absolute viscosity. Viscosity is a measure of the resistance to flow of the liquid at a given temperature. In SI the unit of viscosity is the Pascal second (Pa·s), often conveniently expressed as milliPascal second (mPa·s), which has the English system equivalent of the centiPoise (cP).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration 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[5] 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

[5] The sole source of supply known to the committee at this time is Cannon Instrument Co., 2139 High Tech Rd., State College, PA 16803. 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.