



Designation: D 6821 – 02

An American National Standard

Standard Test Method for Low Temperature Viscosity of Drive Line Lubricants in a Constant Shear Stress Viscometer¹

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1. Scope

1.1 This test method covers the measurement of the viscosity of drive line lubricants (gear oils, automatic transmission fluids, and so forth) with a constant shear stress viscometer at temperatures from –40 to 10°C after a prescribed preheat and controlled cooling to the final test temperature.

1.2 The applicability of this particular test method to petroleum products other than drive line lubricants has not been determined.

1.3 This test method uses the millipascal second (mPa·s) as the unit of viscosity. One millipascal second is equal to one centipoise.

1.4 *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 2983 Test Method for Low-Temperature Viscosity of Lubricants Measured by Brookfield Viscometer²

D 3829 Test Method for Predicting the Borderline Pumping Temperature of Engine Oil³

D 4684 Test Method for Determination of Yield Stress and Apparent Viscosity of Engine Oils at Low Temperature³

3. Terminology

3.1 Definitions:

3.1.1 *apparent viscosity*—the determined viscosity obtained by the use of this test method.

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

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

¹ This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.07.0C on Low Temperature Rheology of Non-Newtonian Fluids.
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² Annual Book of ASTM Standards, Vol 05.01.

³ Annual Book of ASTM Standards, Vol 05.02.

3.1.4 *shear rate*—the velocity gradient in fluid flow.

3.1.4.1 *Discussion*—For a Newtonian fluid in a concentric cylinder rotary viscometer in which the shear stress is measured at the inner cylinder surface (such as the apparatus described in 6.1), and ignoring any end effects, the shear rate is given as follows:

$$G_r = \frac{2 \Omega R_s^2}{R_s^2 - R_r^2} \quad (1)$$

$$G_r = \frac{4 \pi R_s^2}{t(R_s^2 - R_r^2)} \quad (2)$$

where:

G_r = shear rate at the surface of the rotor in reciprocal seconds, s^{–1},

Ω = angular velocity, rad/s,

R_s = stator radius, mm,

R_r = rotor radius, mm, and

t = time for one revolution of the rotor, s.

For the specific apparatus being described in 6.1.1,

$$G_r = \frac{33}{t} \quad (3)$$

3.1.5 *shear stress*—the motivating force per unit area for fluid flow.

3.1.5.1 *Discussion*—For the rotary viscometer being described in 6.1, the rotor surface is the area under shear or the shear area. For this test method, end effects are not considered.

$$T_r = 9.81 M (R_o + R_r) \times 10^{-6} \quad (4)$$

$$S_r = \frac{T_r}{2 \pi R_r^2 h} \times 10^9 \quad (5)$$

where:

T_r = torque applied to rotor, N·m,

M = applied mass, g,

R_o = radius of the shaft, mm,

R_r = radius of the string, mm,

S_r = shear stress at the rotor surface, Pa, and

h = height of the rotor face, mm.

For the dimensions given in 6.1.1,

$$T_r = 32 M \times 10^{-6} \quad (6)$$

$$S_r = 4.5 M \quad (7)$$



3.1.6 *viscosity*—the ratio between the applied shear stress and rate of shear, sometimes called the coefficient of dynamic viscosity.

3.1.6.1 *Discussion*—This value is thus a measure of the resistance to flow of the liquid. The SI unit of viscosity is the pascal second [Pa·s]. The submultiple unit is millipascal seconds (mPa·s).

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *calibration oils*—those oils that establish the instrument's reference framework of apparent viscosity versus speed (angular velocity), from which the apparent viscosities of test oils are determined.

3.2.1.1 *Discussion*—Calibration oils, which are essentially Newtonian fluids, are available commercially and are described in 7.1.

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

3.2.3 *yield stress*—the shear stress required to initiate flow.

3.2.3.1 *Discussion*—For Newtonian fluids and some non-Newtonian fluids the yield stress is very small.

4. Summary of Test Method

4.1 A drive line fluid is preheated to 50°C for a specified time and then cooled at a programmed rate (see Table X1.1) to the final test temperature and soaked at the final temperature for a defined period of time. At the completion of the soak time, the viscosity is measured by applying a prescribed torque and measuring rotational speed to determine the apparent viscosity of the sample.

5. Significance and Use

5.1 Viscosity of drive line lubricants at low temperature is critical for both gear lubrication and the circulation of the fluid in automatic transmissions. For gear oils (GOs), the issue is whether the fluid characteristics are such that the oil will flow into the channel dug out by the submerged gears as they begin rotating and re-lubricating them as they continue to rotate. For automatic transmission fluids, torque, and tractor fluids the issue is whether the fluid will flow into a pump and through the distribution system rapidly enough for the device to function.

5.2 The low temperature performance of drive line lubricant flow characteristics was originally evaluated by the channel test. In this test, a pan was filled to a specified depth of approximately 2.5 cm and then cooled to test temperature. The test was performed by scraping a channel through the full depth of the fluid and across the length of the pan after it had soaked at test temperature for a specified time. The time it took the fluid to cover the channel was measured and reported. The channel test was replaced by Test Method D 2983 in 1971.

5.3 The results of this test procedure correlate with the viscometric measurements obtained in Test Method D 2983.⁴ The correlation obtained is:

$$V = 0.941 \times V_{D\ 2983} \quad (8)$$

where:

V = the apparent viscosity measured by this test method, and

$V_{D\ 2983}$ = the apparent viscosity measured by Test Method D 2983.

5.3.1 The equation was obtained by forcing the fit through zero. The coefficient of variation (R^2) for this correlation is 0.9948.

6. Apparatus

6.1 *Mini-Rotary Viscometer*, an apparatus that consists of one or more viscometric cells in a temperature controlled aluminum block. Each cell, when fitted with the specified rotor, becomes a calibrated rotor-stator set. Rotation of the rotor is achieved by an applied load acting through a string wound around the rotor shaft. The top bearing plate is fitted with locking pins for holding the rotors stationary. Time of rotation is measured electronically by a device attached to the timing wheel.

NOTE 1—The rotors for use with this test method can be distinguished from the rotors used for other mini-rotary viscometer test methods by the white rotor and the white band on the upper half of the shaft. The white band provides rotor identification while the rotor is in the cell.

6.1.1 The mini-rotary viscometric cell for this procedure has the following typical dimensions:

Diameter of rotor	15.0 mm
Length of rotor	20.0 mm
Inside diameter of cell	19.0 mm
Radius of shaft	3.18 mm
Radius of string	0.10 mm

6.2 *Weight*, for applying mass. Weights are to be in increments of 2.5 g $\pm$ 1 %. A minimum of eight weight segments will be needed for the measurements defined in this test method.

6.3 *Temperature Control System*, that will regulate the samples in the cells according to the cooling program described in Table X1.1 and within the tolerances specified in the table.

6.4 *Thermometers*, for measuring the temperature of the block. Two are required, one graduated from at least +40 to 90°C in 1°C subdivisions, and one that has at least a two degree graduated range around the final test temperature in 0.2°C subdivisions. Other thermometric devices of equal or greater accuracy and resolution may be used.

6.5 *Time/Temperature Recording Device*, such as a chart recorder or data logger to verify that the correct cooling of the samples has been accomplished.

7. Reagents and Materials

7.1 *Calibration Oil*, a low cloud-point fluid of approximately 60 000 mPa·s viscosity at –25°C for calibration of the viscometric cells.

7.2 *Oil Solvent*, commercial heptanes or similar solvent for the test fluids that evaporates without leaving a residue. (Warning—Flammable.)

7.3 *Acetone*—A technical grade of acetone is suitable provided it does not leave a residue upon evaporation. (Warning—Flammable.)

⁴ SAE Paper 1999-01-3672, "Viscosity of Drive-Line Lubricants by a Special Mini-Rotary Viscometer Technique." Available from Society of Automotive Engineers, 400 Commonwealth Dr., Warrendale, PA 15096-0001.