Designation: D4683 – 04

# Standard Test Method for Measuring Viscosity at High Shear Rate and High Temperature by Tapered Bearing Simulator[1]

This standard is issued under the fixed designation D4683; 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.

*This standard has been approved for use by agencies of the Department of Defense.*

## 1. Scope*

1.1 This test method covers the laboratory determination of the viscosity of engine oils at 150°C and $1 \times 10^6$ $s^{-1}$ shear rate using a tapered bearing simulator-viscometer (TBS Viscometer)[2] equipped with a refined thermoregulator system. Older TBS units not so equipped must use Test Method D4683–87.

1.2 The Newtonian calibration oils used to establish this test method cover the range from approximately 1.5 to 5.6 cP (mPa·s) at 150°C.

1.3 The non-Newtonian reference oil used to establish this test method has a viscosity of approximately 3.5 cP (mPa·s) at 150°C and a shear rate of $1 \times 10^6$ $s^{-1}$.

1.4 Applicability to petroleum products other than engine oils has not been determined in preparing this test method.

1.5 This test method uses the centipoise (cP) as the unit of viscosity. For information on the equivalent SI unit, the millipascal second (mPa·s) is shown in parentheses.

1.6 *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:*[3]

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

D5481 Test Method for Measuring Apparent Viscosity at High-Temperature and High-Shear Rate by Multicell Capillary Viscometer

## 3. Terminology

3.1 *Definitions:*

3.1.1 *density*—the mass per unit volume. In the SI, the unit of density is the kilogram per cubic metre, but for practical use a submultiple is more convenient. The gram per cubic centimetre is $10^3$ $kg/m^3$ and is customarily used.

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 exhibits a viscosity that varies with changing shear stress or shear rate.

3.1.4 *shear rate*—the velocity gradient in fluid flow. The SI unit for shear rate is the reciprocal second (s-1).

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

3.1.6 *viscosity*—the ratio between the applied shear stress and rate of shear. It is sometimes called the coefficient of dynamic viscosity. This coefficient is thus a measure of the resistance to flow of the liquid. In the SI the unit of viscosity is the pascal second; for practical use, a submultiple, millipascal second, is more convenient. The centipoise is 1 mPa·s and is customarily used.

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

3.1.6.2 *kinematic viscosity*—the ratio of the viscosity to the density of the liquid. It is a measure of the resistance to flow of a liquid under gravity. In the SI the unit of kinematic viscosity is the metre squared per second; for practical use, a submultiple (millimetre squared per second) is more convenient. The centistoke (cSt) is 1 $mm^2/s$ and is customarily used.

3.2 *Definitions of Terms Specific to This Standard:*

[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 on Flow Properties.

Current edition approved Feb. 1, 2004. Published March 2004. Originally approved in 1987. Last previous edition approved in 1996 as D4683–96. DOI: 10.1520/D4683-04.

[2] The sole source of supply of the apparatus known to the committee at this time is Tannas Co., 4800 James Savage Rd., Midland, MI 48642. 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.

[3] 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.

3.2.1 *calibration oils*[2]—Newtonian oils used to establish the reference framework of viscosity versus torque from which is determined the test oil viscosity.

3.2.2 *contact position*—the rotor height when in rubbing contact with the stator.

3.2.3 *idling oil*[2]—an oxidatively stable Newtonian oil used to minimize deposits on the rotor/stator operating surfaces when the instrument is held for long periods of time at operating temperatures of 150°C at which other oils may in reasonably short time decompose and leave residues.

3.2.4 *non-Newtonian reference oil*[2]—a specially selected non-Newtonian reference oil required to establish the proper gap between the rotor and stator to produce an operating shear rate of $1 \times 10^6$ $s^{-1}$.

3.2.5 *reciprocal torque intersection, Rti*—the rotor position on the micrometer defined by the intersection of two straight lines. These are generated by the reciprocal indicated torque versus rotor height for the non-Newtonian NNR-03 and the Newtonian R-400. The intersection indicates the rotor height at which the rotor/stator cell will generate $1 \times 10^6$ $s^{-1}$ shear rate.

3.2.6 *rotor height (rotor position)*—the vertical position of the rotor relative to the stator and measured by the platform micrometer.

3.2.6.1 *Discussion*—For most instruments, a mechanical micrometer is used; the micrometer reading *increases* as the rotor is lowered and approaches the stator. However, if an electronic micrometer is used, the micrometer reading *decreases* when the rotor is lowered.

3.2.7 *stored position*—the rotor position with the rotor 0.50 mm above the contact position.

3.2.8 *test oil*—any oil for which apparent viscosity is to be determined.

## 4. Summary of Test Method

4.1 A motor drives a tapered rotor that is closely fitted inside a matched stator. The rotor exhibits a reactive torque response when it encounters a viscous resistance from an oil that fills the gap between the rotor and stator. Two oils, a calibration oil and a non-Newtonian reference oil, are used to determine the gap distance between the rotor and stator so that a shear rate of $1 \times 10^6$ $s^{-1}$ is maintained. Additional calibration oils are used to establish the viscosity/torque relationship which is required for the determination of the apparent viscosity of test oils at 150°C.

## 5. Significance and Use

5.1 Viscosity at the shear rate and temperature of this test method is thought to be representative of the condition encountered in the bearings of automotive engines in severe service.

5.2 The importance of viscosity at these conditions to engine lubrication has been addressed in many publications.[4]

## 6. Apparatus

6.1 *Tapered Bearing Simulator-Viscometer* [2] (Fig. 1)—a viscometer consisting of a synchronous two-speed motor that drives a slightly tapered bearing in a matched stator (Fig. 2).

6.1.1 The motor and rotor are raised and lowered by means of a platform, which, in turn, is cantilevered from an elevator device. The gap between the rotor and stator is controlled by adjustment of the platform height.

6.1.2 The resistive force of the test oil is transferred to the load cell by the turntable on which the motor sits. This turntable has a projecting arm on which is mounted a contact ball. The rotor is spun by the motor at a constant speed of 50 or 60 r/s depending on the frequency of the alternating current. When the rotor encounters viscous resistance, the reactive force presses the ball against the platen of the load cell to register the resistance given by the viscosity of the oil.

NOTE 1—An automated system for the TBS Viscometer has been developed employing all the steps in the procedure, and it was used for some of the round robin data generated for this test method.

6.2 *Console*—The console shown in Fig. 3 contains the power source for the load cell, thermoregulator circuit, heating coil, and motor. It also contains the circuitry for regulating and monitoring the temperature of the oil in the test cell, as well as the amplifier and digital readout of the load cell response.

NOTE 2—The thermoregulator circuit of the TBS Viscometer has evolved as improvements have been made in the solid-state temperature controller and heater. To achieve the five-minute analysis time specified in this test method requires a late model solid-state controller with automatic reset coupled to a thermofoil heater with small heat inertia or a fast-responding thermoregulated oil bath.[2]

6.3 *Air Circulation System*—A flow of dry compressed air is passed around the stator to provide supplementary cooling when testing fluids of higher viscosity (greater than approximately 9 cP). Ports are provided in the stator housing for the circulation of compressed air.

6.4 *Syringe*, glass or polypropylene (in the latter case, use a non-lubricated plunger), equipped with Luer needle lock to fit the tip of the filling tube for injection of test oil into the annulus between the rotor and the stator.

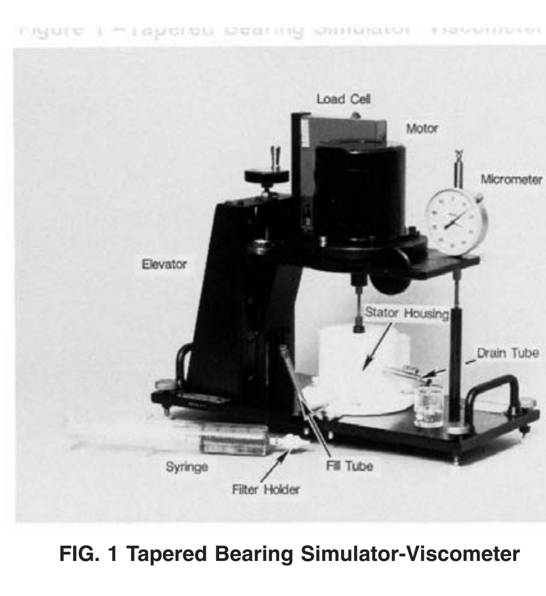


FIG. 1 Tapered Bearing Simulator-Viscometer



[4] For a comprehensive review, see "*The Relationship Between High-Temperature Oil Rheology and Engine Operations*," ASTM Data Series Publication 62.

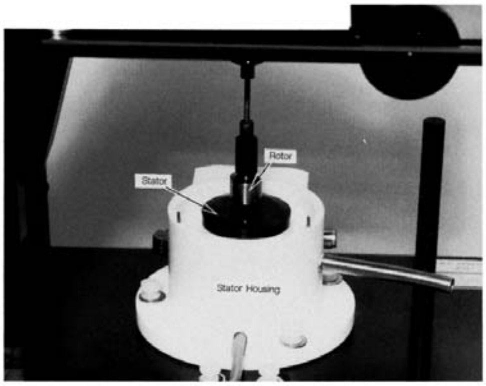


FIG. 2 Rotor, Stator, and Stator Housing

6.5 *Filter*—A filter is used on the syringe to remove particles capable of damaging the rotor/stator cell.[2]

## 7. Materials

7.1 *Calibration Oils* [2] are Newtonian oils of known kinematic viscosity and density at 150°C. The defined viscosities in centipoise (mPa·s) are calculated by multiplying the kinematic viscosity in centistokes by the density in grams per cubic centimetre. Approximate viscosities for the calibration oils are listed in Table 1. Certified viscosities are supplied with each oil.

7.2 *Idling Oil*—See 3.2.3.

7.3 *Non-Newtonian Reference Oil* [2] is essential in setting the rotor/stator gap to $1 \times 10^6$ $s^{-1}$ shear rate. An approximate viscosity of a suitable non-Newtonian reference oil is given in Table 1. The certified viscosity at $1 \times 10^6$ $s^{-1}$ and 150°C is supplied with the oil and is matched to the viscosity of reference fluid R-400 (see Table 1).

## 8. Sampling

8.1 A representative sample of test oil is obtained. When used oils are evaluated, it is desirable to change the filter attached to the syringe periodically to reduce injection pressure caused by particle buildup on the filter surface.

NOTE 3—Precision for used oils has not been determined.

## 9. Preparation of the Apparatus

9.1 Directions for preparation of the tapered bearing simulator-viscometer and console are supplied with the equipment. One of the most important directions to be followed is the alignment of the rotor/stator before initial use of the viscometer.

9.2 With continuous use, a weekly room-temperature flush of the rotor/stator cell is recommended following directions in 11.4.

## 10. Calibration

10.1 Proceed to Section 11 if the operating position has already been established.

10.2 *Activating the Console*—Be sure the MOTOR switch on the console is in the OFF position. Then, turn on the POWER switch. Leave the console in this standby condition for at least 1 h before using the tapered bearing simulator-viscometer.

10.3 *Oil in Test Cell*:

10.3.1 If there is no oil in the test cell, slowly inject 50 mL of the idling oil or other suitable oxidation-resistant fluid.

10.3.2 When there is oil in the test cell, proceed with the determination of the stored position as described in 10.4. If this position has been determined, proceed to 10.5.

10.4 *Determining the Stored Position*:

10.4.1 Bring the operating temperature to 150°C by setting the thermostat on the console.

10.4.2 Be careful not to touch the hot upper stator surface when the following operation is performed. Slowly lower the rotor into the stator by means of the height adjustment wheel on the elevator assembly while turning the flexible shaft connecting the motor and the rotor with the fingers until slight rubbing contact is felt between the rotor and the stator. Then slowly continue to lower the rotor in small increments (approximately 1⁄10 of the smallest division or 0.001 mm until further turning is prevented (without forcing rotation)). This is the point of rubbing contact. Record the micrometer reading to the third decimal place (that is, estimate the last place from the needle position between the minor division marks). *All subsequent readings of the micrometer dial will be to the nearest 0.001 mm.*

10.4.3 Raise the rotor to a position 0.50 mm (500 micrometres) above the contact position. Record this reading as the stored position.

10.4.3.1 It is important to observe whether the micrometer reading is 0.50 mm *smaller* or 0.50 mm *larger* than the reading at the contact position. For units that have mechanical micrometers, the reading for the stored position will be 0.50 mm smaller than that recorded for the contact position. If an electronic micrometer is used, the reading for the stored position will be 0.50 mm larger than that recorded for the contact position. See 3.2.6.1.

10.5 *Determination of the Reciprocal Torque Intercept (Rti) to Determine Rotor Position for $1 \times 10^6$ $s^{-1}$ Shear Rate*:

10.5.1 With the rotor in the stored position, gently move the motor turntable clockwise a few degrees to disengage the ball from contact with the platen, hold the motor housing firmly in this position, set the speed switch to HI and flip the motor switch to the ON position. Release the grip on the motor and let the reaction torque of the spinning motor bring the ball into contact with the load cell platen (See Fig. 4).

10.5.2 Let the motor run at least 1 h before proceeding to 10.5.3.

10.5.3 Fill the test cell with NNR-03 non-Newtonian reference oil by either of the methods described in 10.5.3.1 or 10.5.3.2. See Section 8 for sampling precautions. After the test cell has been filled, all subsequent injections should be made with the motor running. (If this is a first time operation or after the viscometer has been idled for more than an hour, make a second injection after waiting the requisite 5 min 30 s.)

10.5.3.1 Fill the syringe with 50 ± 3 mL of oil. Slowly inject the oil into the inlet tube of the test cell at a rate of