Designation: D 6616 – 01

An American National Standard

Standard Test Method for Measuring Viscosity at High Shear Rate by Tapered Bearing Simulator Viscometer At 100°C[1]

This standard is issued under the fixed designation D 6616; 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 laboratory determination of the viscosity of engine oils at 100°C and $1\bullet10^6s^{-1}$ using the Tapered Bearing Simulator (TBS) viscometer.[2]

NOTE 1—This test method is similar to Test Method D 4683 which uses the same TBS viscometer to measure high shear viscosity at 150°C.

1.2 The Newtonian calibration oils used to establish this test method range from approximately 5 to 12 mPa•s (cP) at 100°C and either the manual or automated protocol was used by each participant in developing the precision statement. The viscosity range of the test method at this temperature is from 1 mPa•s (cP) to above 25 mPa•s (cP), depending on the model of TBS.

1.3 The non-Newtonian reference oil used to establish the shear rate of $1\bullet10^6s^{-1}$ for this test method has a viscosity of approximately 10 mPa•s at 100°C.

1.4 Application to petroleum products other than engine oil has not been determined in preparing the viscometric information for this test method.

1.5 This test method uses the milliPascal second (mPa•s) as the unit of viscosity. This unit is equivalent to the centiPoise (cP), which 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 to determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 4683 Test Method for Measuring Viscosity at High Shear Rate and High Temperature by Tapered Bearing Simulator[3]

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 equivalent to 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 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 the rate of shear. It is sometimes called the coefficient of dynamic viscosity. This coefficient is a measure of the resistance to flow of the liquid. In the SI, the unit of viscosity is the Pascal•second; often the milliPascal•second or its equivalent the centiPoise is found more convenient.

3.1.6.1 *apparent viscosity*—the viscosity of a non-Newtonian fluid at a given shear rate or shear stress determined by this test method.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *idling oil*[2]—an oxidatively stable Newtonian oil injected into the operating viscometer stator when the instrument is likely to be held for periods of time greater than 30 min and up to two weeks at 100°C. Use of this oil prevents stator deposits from additives, which may decompose after longer exposure times in the operating viscometer and permits continuous operation of the viscometer without need to shut the instrument off.

3.2.2 *Newtonian Reference Oil*[2]—a specially blended Newtonian oil that has the same viscosity at 100°C as the non-Newtonian reference oil of 3.2.3.

3.2.3 *non-Newtonian reference oil*[2]—a specially formulated non-Newtonian oil, identified as NNR-10, having a selected apparent viscosity at $1\bullet10^6s^{-1}$ shear rate. The oil is used to establish an operating gap between the rotor and stator which will produce $1\bullet10^6s^{-1}$ shear rate when the rotor height is

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

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[2] Available from Tannas Co., 4800 James Savage Rd., Midland, MI 48642. This viscometer and associated equipment as listed in the research report was used to develop the precision statement. To date, no other equipment has demonstrated, through ASTM interlaboratory testing, the ability to meet the precision of this test. This is not an endorsement or certification by ASTM.

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

adjusted to give a torque output equivalent to that of the special reference oil described in 3.2.2.

3.2.4 *reciprocal torque intersection, $1/T_i$*—the rotor position on the micrometer defined by the intersection of two straight lines generated by the reciprocal torque method using the Newtonian reference oil of 3.2.2 and non-Newtonian reference oil of 3.2.3. Reciprocal torque versus rotor height measurements on both oils gives straight lines whose intersection, $1/T_i$, establishes the desired rotor position for operation at $1 \cdot 10^6 s^{-1}$ shear rate.

3.2.5 *reference Newtonian calibration oils*[2]—specially chosen Newtonian oils used to determine the viscosity-torque relationship of the TBS viscometer at 100°C from which the viscosity of an unknown oil is calculated.

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 *stored rotor height (rotor position)*—the rotor position with the rotor 0.50 mm above the rubbing contact position (see 3.2.7) when the instrument is shut down.

3.2.7 *rubbing contact position*—the rotor height determined when the tapered rotor is lightly brought into contact with the similarly tapered stator.

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

4. Summary of Test Method

4.1 A motor drives a tapered rotor closely fitted inside a matched tapered stator. Appropriate technique establishes operation of the viscometer to yield $1 \cdot 10^6 s^{-1}$ at a temperature of 100°C at which point test oils are introduced into the gap between the spinning rotor and stationary stator. The rotor exhibits a reactive torque to the viscous resistance of each test oil and the value of this torque response is used to determine the apparent viscosity of the test oil at 100°C.

5. Significance and Use

5.1 Viscosity at the shear rate and temperature of this test method is thought to be particularly representative of bearing conditions in large medium speed reciprocating engines as well as automotive and heavy duty engines operating in this temperature regime.

5.2 The importance of viscosity under these conditions has been stressed in railroad specifications.

6. Apparatus

6.1 *Tapered Bearing Simulator Viscometers*[2] *(TBS)*—a viscometer consisting of a motor connected to a slightly tapered rotor that fits into a matched stator. Several models of the TBS are in use. All of these are capable of analyzing test oils at 100°C but earlier models are more limited in their upper viscosity range.

6.2 Different models of the tapered bearing simulator (TBS) have the following upper levels of operating viscosities at $1 \cdot 10^6 s^{-1}$ shear rate:

6.2.1 Model Series 400 (similar to Fig. 1)—~14 mPa•s (cP), dual speed.

6.2.2 Model Series 500 (Fig. 1)—~ 16 mPa•s (cP) single speed.

6.2.3 Model Series 600 (Fig. 2)—~100 mPa•s (cP) (usually liquid cooled), dual speed.

6.2.4 Model Series SS (SuperShear) (similar to Fig. 1)—

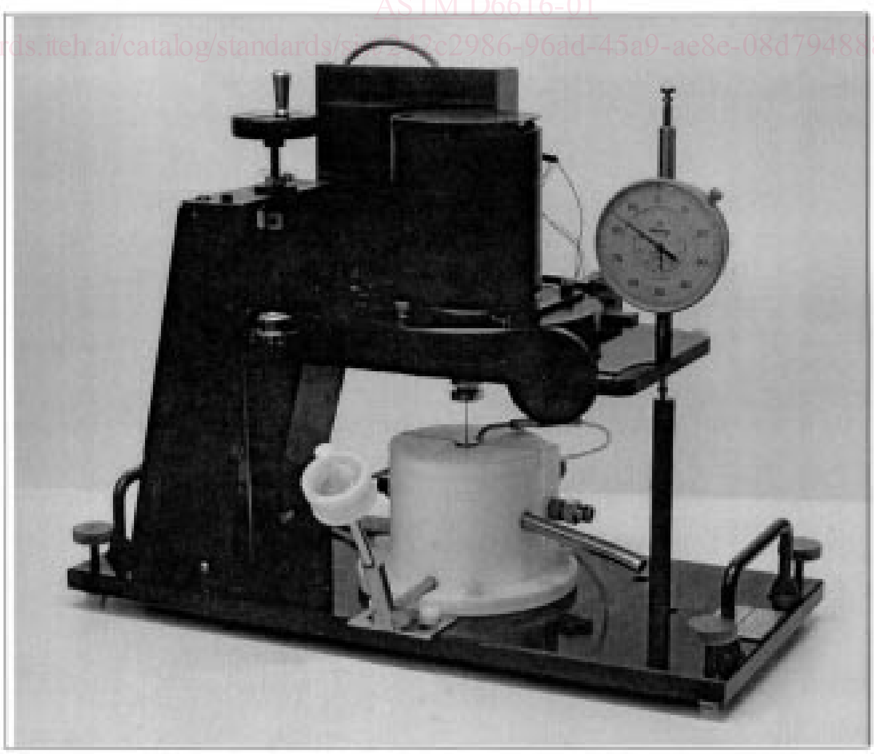

FIG. 1 Tapered Bearing Simulator Viscometer Model 500

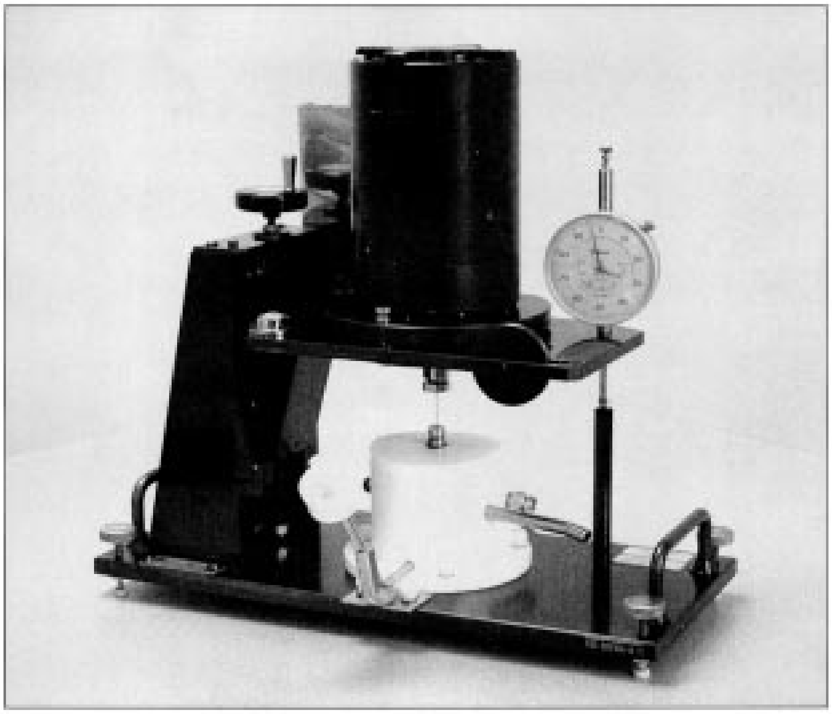

FIG. 2 High Torque Tapered Bearing Simulator Viscometer Model 600

~20 mPa•s (cP), multi-speed.

6.2.5 Model Series 2100 E (Fig. 3)—~20 mPa•s (cP) (see Note 2), multi-speed.

NOTE 2—TBS Models 500, 600, and SS use a so-called *bouncer* to automate unloading and reloading the load cell just before taking a torque reading. (All automated units apply the bouncer at the appropriate point of operation as part of their program.) If a bouncer is not on the TBS model used (Model 400), the effect is generated by placing the thumb on the brass weight pin and turning the turntable slightly in a clockwise direction and quickly releasing the turntable. The bearingless Models 2100 E do not require unloading the cell since there is no turntable bearing.

6.3 *Automated System for Calibration, Injection, and Data Analysis Programs*—An automated program for the Tapered Bearing Simulator, simulating the manual method has been used.

6.4 *Console*—The console shown in Fig. 4 is similar in Models 400, 500, and 600. Consoles for Series SS and 2100 E have provisions for changing motor speed. All consoles contain the power source for the load cell, thermoregulator circuit, stator-heating element, and motor. They also contain the circuitry for regulating and monitoring the temperature of the oil in the stator as well as the amplifier and digital readout of the load cell.

NOTE 3—The thermoregulator circuit of the TBS viscometers has evolved as improvements have been made in the solid-state temperature controller and heater. To achieve the 5 min analysis time specified in this test method requires a late model solid-state controller with automatic reset coupled to a thermo-foil stator heater with small heat inertia or a fast-responding thermoregulated liquid bath.[2]

6.5 *Cooling Systems*—Two cooling systems are available for TBS viscometer work at 100°C – forced air cooling and liquid bath cooling. The stator housing is prepared for the former but must be modified for the latter according to directions from the manufacturer.

6.6 *Glass Syringe*—A 50-mL glass syringe equipped with a Luer needle lock fits the tip of the filling tube for injection of test oil into the test cell. Smaller glass and plastic syringes can be used if any air bubble in the fill tube caused by the exchange of syringes is first pulled up into the next syringe to be used.

6.7 *Filter Assembly*—A unit made of a filter holder[2] and nominal 10-μ filter[2] is interposed between the syringe and the filling tube to remove particles capable of damaging the rotor/stator cell.

6.8 *Data Recording Equipment*—Some form of recording the torque and temperature data produced by the tapered bearing simulator is desired in order to (*1*) determine torque/temperature equilibrium and (*2*) determine the torque with sufficient precision to calculate viscosity to the second decimal place. Early in the use of the TBS viscometer, a strip-chart recorder was used, later an automated, computer-based recording system was developed with both a computer-simulated strip chart and with data digitally recorded.

NOTE 4—Although the console has a torque indicator that can be used for determining viscosity, it has been found that the small oscillatory variation of torque with time makes desirable the recording and analysis of the torque output more precise, particularly when determining torque equilibrium.

6.8.1 *Strip-chart Recorder*:

6.8.1.1 If a strip-chart recorder is used to record the torque and temperature output signals, use the manufacturer's directions for calibrating and setting up the strip chart for recording torque/temperature data (see Note 5). The torque reading must be in milliVolts and the temperature in °C with a full-scale

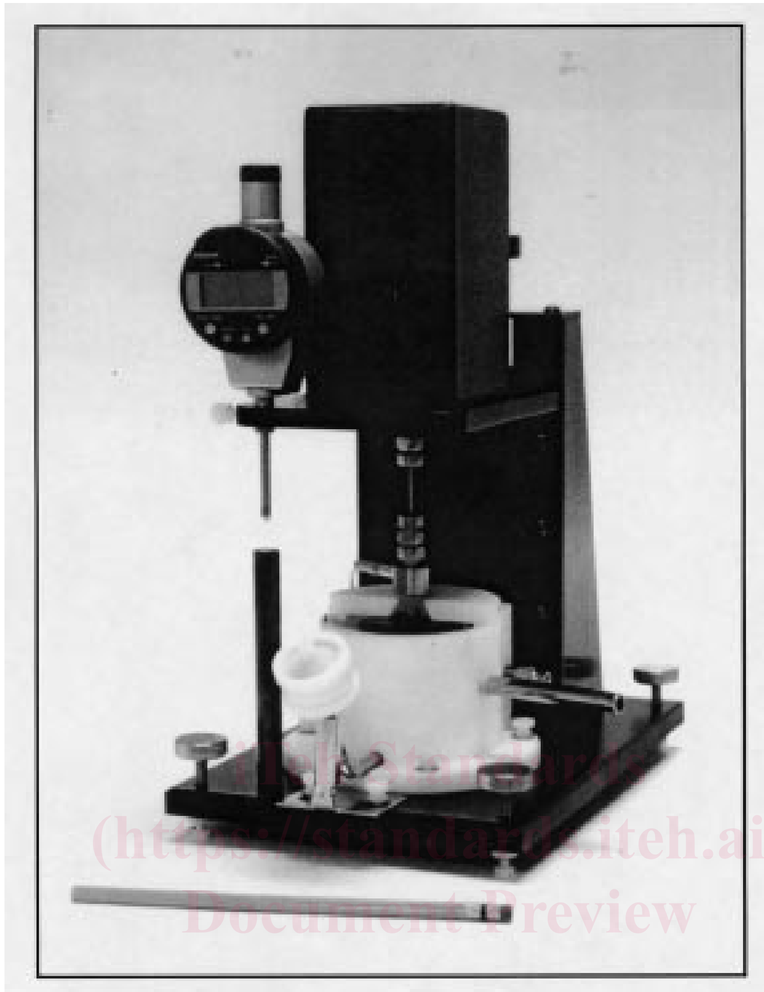

FIG. 3 Multi-Speed Tapered Bearing Simulator Viscometer Model 2100E

FIG. 4 Control Console for Tapered Bearing Simulator Viscometer Models 400, 500, and 600

chart range of 20° to 120°C.

6.8.1.2 Use a chart speed of 1 cm/min for recording.

6.8.1.3 Set and, when necessary, reset, the strip chart torque voltage to that which will permit recording the torque as much as possible on the upper two-thirds of the chart paper for maximum sensitivity.

6.8.1.4 Factor the resulting voltage values to calculate the correct values of torque.

NOTE 5—Although the digital information from the torque output meter on the viscometer console can be, and is, used for recording additional test information, it is desirable to use a two-pen, strip-chart recorder or its computer equivalent since this provides a continuous torque/temperature record of torque/temperature equilibrium necessary for precision in calibration and in calculating viscosity.

6.8.2 *Computer Accumulation of Torque and Temperature Data*—Computer recording of digital data can also be used for the test method. Such programs should show data for both torque and stator temperature. Torque information should be capable of permitting the calculation of viscosity to the second decimal place.