Designation: D 2983 – 04a

An American National Standard

Standard Test Method for Low-Temperature Viscosity of Lubricants Measured by Brookfield Viscometer[1]

This standard is issued under the fixed designation D 2983; 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 use of the Brookfield viscometer and a low-temperature bath for the determination of the low-shear-rate viscosity of lubricants. The test may operate in the viscosity range of 500 to 1 000 000 mPa·s (cP). The bath-controlled temperature is selected within the range of +5° to –40°C.

1.2 The test method uses the SI unit, milliPascal-second (mPa·s), as the unit of viscosity. (1 cP = 1 mPa·s).

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

[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.

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***A Summary of Changes section appears at the end of this standard.**

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 341 Standard Viscosity-Temperature Charts for Liquid Petroleum Products

2.2 *European Procedure:*

CEC L18-A-80[3]

2.3 *ASTM Adjuncts:*

ADJD6300 D2PP, Version 4.43, Determination of Precision and Bias Data for Use in Test Methods for Petroleum Products[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *apparent viscosity*—the dynamic viscosity determined by this test method. Apparent viscosity may vary with the spindle speed (shear rate) of the Brookfield viscometer if the lubricant is non-Newtonian at low temperatures. See Appendix X1 for a brief explanation.

3.1.2 *reference viscosity*[5,6]—the viscosity of a Newtonian standard reference fluid specified at each of several user-specified temperatures. Reference viscosities of typical standard reference fluids are listed in Appendix X2.

4. Summary of Test Method

4.1 A lubricant fluid sample is preheated, allowed to stabilize at room temperature, and then poured into a glass cell with a special spindle. The glass cell is then placed into a pre-cooled cold cabinet set at a predetermined test temperature between +5 to –40°C for 16 h. Then a viscometer is utilized that rotates the specified spindle within the sample at the speed giving a maximum torque reading on the viscometer. The resulting torque reading is used to calculate the viscosity of the oil.

5. Significance and Use

5.1 The low-temperature, low-shear-rate viscosity of gear oils, automatic transmission fluids, torque and tractor fluids, and industrial and automotive hydraulic oils, Annex A4, are of considerable importance to the proper operation of many mechanical devices. Measurement of the viscometric properties of these oils and fluids are often used to specify their acceptability. This test method is used in a number of specifications.

5.2 This test method describes how to measure apparent viscosity directly without the errors associated with either interpolation or extrapolation of experimental data.

NOTE 1—Viscosity values obtained by either interpolation or extrapolation are subject to errors caused by gelation or non-Newtonian response to rotor speed, or both. Only in the case of known Newtonian oils is interpolation acceptable for the purpose of calibrating the rotor and glass cell. If such viscosity versus temperature plots are required, they can be made by the procedure outlined in Annex A1.

6. Apparatus

6.1 *Brookfield Viscometer*[6,7]—Analog Model LVT or more recent digital models (for example, LVDV-II+) are ~~required.~~

~~NOTE 2—Make~~ required. Make certain that the viscometer is calibrated and in good working order prior to operation.

[2] 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.

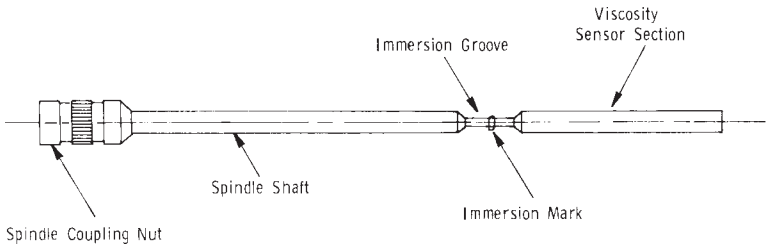
[3] Available from CEC, Mandou Plaza-25th Floor, B-1210 Brussells, Belgium.

[4] Available from ASTM International Headquarters. Order Adjunct No. ADJD6300.

[5] The sole source of supply of the Standard Newtonian Brookfield viscosity reference fluids known to the committee at this time is Cannon Instrument Co., Post Office Box 16, State College, PA 16801.

[6] 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.

[7] The sole source of supply of the Brookfield viscometer and accessories known to the committee at this time is Brookfield Engineering Laboratories, Inc., Stoughton, MA 02072.



NOTE—Adapted from drawings of Brookfield Engineering Laboratories.

FIG. 1 Diagram of No. 4 LV Cylindrical Spindle

6.2 *Viscometer Spindle*[6,7]—Uninsulated viscometer No. 4 spindle or insulated No. 4B2 spindle may be used. Periodically (depending on use, but at least every 3 months) inspect for wobble of the spindles. The run-out (wobble) of the spindle must not exceed 1 mm. Contact the manufacturer for measuring details. For No. 4B2 spindles, ensure firm adhesion of the lower part of the spindle. A number of spindles are needed for multiple determinations. See Fig. 1 for diagram.

6.3 *Spindle Clip*[6,8]—A thin clip or spacer that supports the spindle at proper immersion depth during cool-down.

6.4 *Test Cell*[6,8]—A glass test tube 22 to 22.5 mm in inside diameter and 115 ± 5 mm in overall length.

6.5 *Cell Stopper*[6,8] (Fig. 2)—A cap that fits onto the test cell with a hole large enough for the spindle to turn with sufficient clearance.

6.6 *Insulated Cell Carrier*[6,8] (Fig. 2) —A balsa wood block with windows that keeps the test cell cold during testing.

NOTE ~~3~~2—A liquid bath,[6,8] with a viewing window, held at the specified temperature, within 0.1°C, can be used in place of the test cell carrier (see also Note 1~~1~~0).

6.7 *Cold Cabinet*[6,8]—A top-opening cold cabinet with an air-circulation device may be used (see Note ~~4~~). 3). To minimize disturbance, it is recommended that the cabinet has an inner cover with hand-holes for sample insertion and removal. The cold cabinet must cool the sample to a chosen constant test temperature over a range from +5° to –40°C and hold that temperature within ± 0.3°C. The air circulation device and the turntable must be able to be switched off prior to fully opening the bath top. Mechanically refrigerated liquid baths may be used for apparent viscosity determinations. A European procedure, CEC L18-A-80, describes the use of such baths. A liquid bath can be used for sample conditioning if it can duplicate the sample cooling rates outlined in Annex A2. The main advantage of a liquid bath over an air bath is more precise temperature control and thus more precise apparent viscosity measurement.

NOTE ~~4~~3—Liquid baths are available that can cool at the proper rate and maintain the selected test temperature within 0.1°C of the set point for the 16-h soak-period portion of the test. Details on liquid baths can be found in the manufacturer's manual.

6.8 *Turntable*[6,8]—This device contains the cell rack. The turntable should rotate at a speed of 3 to 5 rpm. This item is often supplied with the cold cabinet. The turntable is not required for a liquid bath.

[8] The sole source of supply of these items known to the committee at this time is Lawler Manufacturing, Inc., 7 Kilmer Ct., Eddison, NJ 08817.

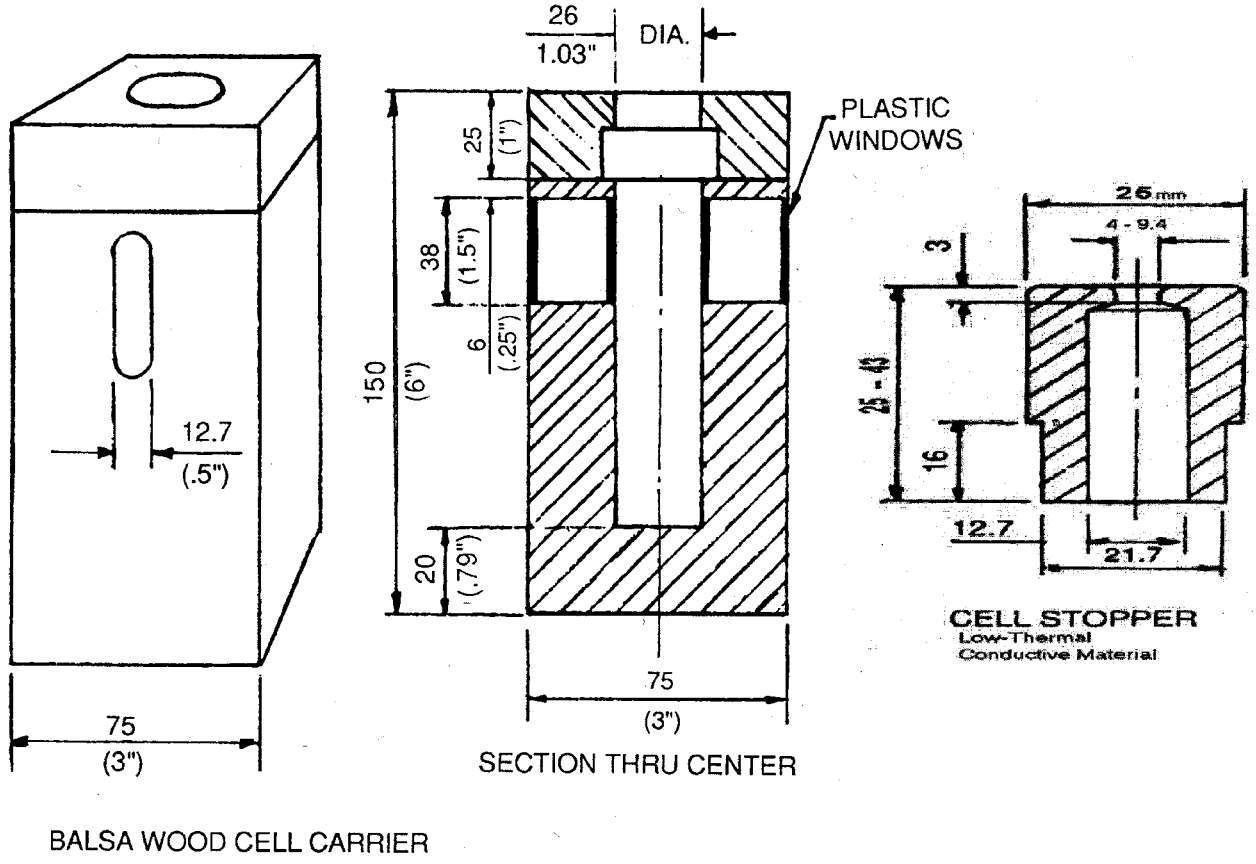


FIG. 2 Cell Stopper

6.9 *Temperature Sensing Devices* —Use certified or other calibrated thermometric devices of equal or greater accuracy that cover the range from +5° to –40°C with 0.1°C (or finer) increments. For air-bath-style cold cabinets, it is recommended to use IP Brookfield Viscometer Total Immersion Thermometers:

IP 94C	–45° to –35°C	ASTM 122C
IP 95C	–35° to –25°C	ASTM 123C
IP 96C	–25° to –15°C	ASTM 124C
IP 97C	–15° to –5°C	ASTM 125C

and ASTM 63C (–8° to +32°C)) in conjunction with a calibrated resistance temperature detector (RTD) device. The RTD must be effectively calibrated at 0°C and –40°C. The thermometers can be compared to the RTD in order to get an accurate reading. Store thermometers in an upright position to help maintain calibration. Make certain that there are no separations in the column.

6.9.1 For liquid baths, use certified or other calibrated thermometric devices of equal or greater accuracy that cover the range from +5 to –40°C with 0.1°C (or finer) increments (consult the bath manufacturer for calibration details). As with the air bath, compare these results with an RTD in order to verify an accurate reading. For further verification of the temperature control in air or liquid baths, see Annex A4.

6.10 *Blank Sample*— A fluid that is close in chemistry to those being tested for the purpose of determining the temperature experienced within a sample.

7. Use of Reference Fluids

7.1 The use of standard reference fluids, detailed in Annex A3 and Annex A4, was developed to ensure more precise control of the apparent viscosity measurements. Each new spindle should be run with a reference oil prior to testing samples to ensure accurate results. With analog viscometers, the procedure to calculate expected reference fluid dial readings and interpret observed reference fluid dial readings is given in Annex A3. Although the dial reading limits listed in Annex A3 are typical of the data received from several extensive round robins, more precise control is both desirable and possible with digital equipment.

8. Procedure

8.1 *Preparation of the Bath*:

8.1.1 Set the test temperature of the cold cabinet, monitor the temperature with a blank sample, and allow the bath to stabilize at the desired test temperature. Do not put any test samples in the turntable.

8.1.2 After equilibration, check the bath temperature by the thermometer or thermometric device immersed in a blank sample of oil held by the rotating rack.

NOTE 5~~4~~—If a temperature adjustment is made, it may require at least 1 h for temperature equilibration. Depending on specific bath characteristics, longer times for equilibration may be required after major temperature changes. Do not adjust bath temperature after 4 h into the sample-conditioning period because the apparent viscosity of the sample may be significantly changed.

8.2 *Preparation of Sample*:

8.2.1 Shake the sample container thoroughly and place about 30 mL into the test cell. It is essential that the appropriate reference fluids be run at the beginning and end of each test series (and results recorded) to indicate the sample temperature change that results from frequent opening of the cold cabinet. Reference fluids do not require pre-conditioning; however, they should be handled in the same manner as the test fluids in all other ways. Annex A4 details the calculation of the apparent run temperature from reference fluid viscosity and rpm data. The change in apparent run temperature (from run to run) may not exceed 0.4°C. The apparent run temperature itself should be within ±0.3°C of the set test temperature.

NOTE 6~~5~~—If the apparent viscosity of the sample is unknown, use two samples, one for determination of the rpm and one for determination of apparent viscosity.

8.2.2 Cover each sample (such as with aluminum foil). Maintain the sample at 50 ± 3°C for 30 ± 5 minutes. If using a liquid bath, then cover each sample with an airtight seal (such as a finger cot).

NOTE 7~~6~~—This preheating step has been proven important in other critical low-temperature ASTM methods and is designed to remove any memory effects that may develop from previous low-temperature exposures or structure formations. Higher temperatures and longer preheating times are being explored.

8.3 Remove the test cells from the heating source and allow to cool to room temperature (25 ± 5°C) and then remove the covers.

8.3.1 Cover the test cell (6.4) with the cell stopper (6.5) and use the spindle clip (6.3) to support the spindle (6.2) and lower into the test cell so that the center of the spindle immersion mark is slightly below the liquid surface (to allow sample shrinkage due to cooling). This reduces the amount of disturbance placed on the sample before measurement later in the method. See Fig. 1 for diagram.

NOTE 8~~7~~—Handle and store the spindles and instrument with care at all times. Check the calibration of each spindle periodically with reference oil (see Section 7). Do not use any damaged or noticeably bent spindles.

8.4 Put the test cells and insulated test cell carriers into the cold cabinet. So as not to restrict airflow within the air chamber, do not put too many cell carriers into the air chamber. This can be checked by contacting the cold cabinet manufacturer.

8.5 Once the last cell has been loaded, let the sample soak for no less than 16 h. Experience has shown that 6 h is a sufficient soak time for automatic transmission fluids at –17.8°C. Since this shorter soak time speeds data production and is used in some

automatic transmission fluids specifications, it is the only exception to the 16-h soak time allowed by this test method (see 8.10).

8.6 During the soak period, align the viscometer by using the bubble level located on the viscometer.

8.6.1 After turning on the power, zero the viscometer with no spindle attached (some digital models have an auto-zeroing feature).

8.6.2 For digital viscometers select the S64 spindle selection or the setting that corresponds to the No. 4 or No. 4B2 spindles. After selecting the S64 spindle, immediately press the spindle selection key again to store the change. Failure to press the spindle selection key within 2 s will cause the viscometer to retain the last spindle used and therefore may lead to the use of the wrong spindle selection.

NOTE ~~9~~8—Refer to the viscometer manufacturer for more detailed instructions on viscometer care and calibration.

8.7 After the 16-h soak is complete, individually transfer and test the samples as follows (It is essential that the procedure be followed in detail for the proper operation of this test):

8.7.1 Check the level of the viscometer.

NOTE ~~10—It~~ 9—It is very important that the viscometer be level during measurement.

8.7.2 Record the temperature of the blank sample.

8.7.3 Turn the turntable rotation and the air blower off.

8.7.4 Allow the air blower and the turntable to come to a complete stop then open the cold cabinet and put one temperature-conditioned test cell into a temperature-conditioned insulated cell carrier and remove from the cold cabinet.

NOTE 1~~1~~0—If the laboratory is equipped with a low-temperature liquid bath capable of maintaining test temperature within ±0.1°C and on which the Brookfield viscometer can be conveniently mounted, a cell may be removed from the cold cabinet after 15.5 h and placed in the liquid bath at test temperature for 30 min. The apparent viscosity can then be measured directly on the sample in the cell in the liquid bath without haste and without fear that the sample will warm up as it does in the cell carrier. An insulated spindle is needed if this procedure is used.

8.7.5 Close the cold cabinet lid, immediately restart the turntable and air blower and transfer the insulated cell carrier with the sample to the viscometer.

8.7.6 Place the test cell carrier with test cell below the viscometer and align the spindle nut with the viscometer coupling nut, attach the spindle, and remove the spindle clip being sure to minimize the disturbance of the sample with the spindle.

8.7.7 Select the viscometer display mode to read either as percent of scale or directly as mPa·s.

8.7.8 Look through the windows on the test cell carrier and adjust the assembly until the oil level is even with the immersion mark on the spindle shaft. In order to facilitate the adjustment of the spindle, place a cool light source, such as a flashlight, behind one window of the test cell carrier. Great care must be taken to ensure proper spindle immersion with all samples. Maintenance of proper immersion depth is essential to good reproducibility and repeatability.

NOTE 1~~2~~1—Data show that an immersion variation of as little as 1.2 mm from the immersion mark can produce viscosity errors.

8.7.9 Center the spindle in the hole at the top of the cell stopper, making certain that no part of the spindle touches the stopper hole during the measurement process.

8.8 Turn on the viscometer motor and take readings from the digital viscometer as follows:

8.8.1 Refer to Section 9 for the proper rpm setting. Use the highest viscosity reading after the first 5 s of rotation.

8.8.2 Record viscosity reading (mPa·s), spindle speed (rpm), and test temperature (°C).

8.9 For the best precision results, testing should be started within 30 s after the sample is removed from the cold cabinet. The measurement shall be complete in no longer than 60 s (or 90 s for samples with viscosities higher than 150 000 mPa·s). Take two readings and record the higher of the two (see Table 1 for speed/viscosity selections). If using a digital viscometer, monitor the reading during the entire measurement and record the highest value. The urgency in this measurement is required to minimize sample temperature increase and erroneously low viscosities. If using an analog dial viscometer, see Table 2 for test times.

8.10 The total test series must be completed within 2 h so that the maximum soak time of 18 h is not exceeded.

8.11 After using the first cell carrier, return it to the bath for reconditioning and use the others in turn if necessary for further testing.

TABLE 1 RPM Selection Chart

NOTE—If determined apparent viscosity is below range indicated for rpm, use next higher rpm.

Spindle Speed, rpm	Multiply torque by below number to calculate viscosity at speed selection used	Viscosity Range, mPa·s
0.6	10 000	400 000 to 1 000 000
1.5	4000	200 000 to 400 000
3.0	2000	100 000 to 200 000
6.0	1000	50 000 to 100 000
12.0	500	20 000 to 50 000
30.0	200	9800 to 20 000
60.0	100	500 to 9800

TABLE 2 Standardized Observation Times

rpm	Maximum Observation Time, (min)	Maximum Spindle Rotations	Record
0.6	5	3	Highest dial reading seen as the scale pointer passes instrument window during observation time.
1.5	3	4.5	
3.0	3	9	
6.0	2	12	Highest dial reading seen during observation time.
12.0	1	12	
30.0	30s	15	Observe dial reading at end of 30 s. Do this twice and record the higher reading.
60.0	30s	30	

NOTE 132—Frequent opening of the cold box during a long series of runs may cause a temperature rise in the test samples. It is essential to turn the air circulation device off and allow it to come to a complete stop before opening the top. Do not leave the top open unnecessarily. The test series should be run as quickly as possible.

8.12 Upon completion of testing, empty the cells and clean all parts with a suitable hydrocarbon solvent making sure all parts are clean and free of oil.

9. RPM Selection

9.1 Because many lubricant fluids are non-Newtonian at low temperatures, the rpm selected for a measurement can strongly influence the resultant viscosity (see Appendix X1). For this reason, Table 1 lists the viscosity range for each rpm.

9.2 If an expected apparent viscosity is known, use the highest rpm corresponding to the known viscosity range. Table 1 must be used in selecting the appropriate rpm. Table 1 also provides the multiplication factor for viscometers without a viscosity readout or if the older analog viscometer is used. Simply multiply the torque display or the dial reading by the number provided for the speed selections used. Make certain that the torque value (or dial reading) is as close to mid-range as possible (that is, 50).

9.3 If the expected viscosity range of the sample is unknown, a first sample must be used to determine the highest rpm that gives an acceptable viscometer reading. This is accomplished by increasing speed in steps from 0.6 to 60 rpm. The second sample is then run at the previously determined speed and only this result is reported.

10. Calculation

10.1 For viscometers without direct viscosity readout, calculate the viscosity at the test temperature of the test oil or reference oil as shown in Table 1.

10.2 The shear stress and shear rate at the surface of the Brookfield spindle may be estimated by the procedure in Appendix X3.

11. Report

11.1 A routine report includes the apparent viscosity, the test temperature, and the test rpm. RPM data are needed to ensure that different laboratories use the same shear rates.

11.2 In cases where this test method is used for reference testing, a full report of the Newtonian reference fluid, its reference viscosity, its apparent viscosity, and its test rpm must accompany the test fluid data of 9.3. Reference fluid data are needed to ensure that different laboratories run at the same temperature, shear rate, and viscometric conditions.

12. Precision and Bias

12.1 *Statement of Precision*:

12.1.1 *Repeatability*— The difference between successive test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, and in the normal and correct operation of the test method, exceed the values indicated below only in one case in 20.

$$\text{Repeatability} = 3.79\ (X/1000)^{1.7}$$

where:

X = the apparent viscosity, in mPa·s.

12.1.1.1 *For Example Only*— the following shows the repeatability at several viscosities:

20 000 mPa·s: 616 mPa·s
50 000 mPa·s: 2 930 mPa·s
100 000 mPa·s: 9 520 mPa·s
200 000 mPa·s: 30 930 mPa·s

12.1.2 *Reproducibility*— The difference between two single and independent results, obtained by different operators working in different laboratories on identical test material would, in the long run, and in the normal and correct operation of the test method, exceed the values indicated below only in one case in 20.

$$\text{Reproducibility} = 11.34\ (X/1000)^{1.7}$$

where
X = the apparent viscosity, in mPa·s.

12.1.2.1 *For Example Only*— the following table shows the reproducibility at several viscosities:

20 000 mPa·s: 1 850 mPa·s	100 000 mPa·s
28 560 mPa·s	
50 000 mPa·s: 8 790 mPa·s	200 000 mPa·s
92 790 mPa·s	

12.1.3 No information can be presented on the bias of the procedure in Test Method D 2983 for measuring viscosity because no material having an accepted reference value is available.

12.2 *General Considerations*:

12.2.1 The interlaboratory study for the above precision statement was made on two groups of samples. For viscosities within the range of 500 to 1700 mPa.s, 6 hydraulic oils were evaluated in ten laboratories. For viscosities within the range of 17 000 to 200 000 mPa.s, 8 formulated oils were tested in eleven laboratories.

12.2.2 All laboratories utilized Brookfield viscometers for analysis.

ANNEXES

(Mandatory Information)

A1. DETERMINATION OF THE BROOKFIELD VISCOSITY VERSUS TEMPERATURE FUNCTION OF AUTOMOTIVE FLUID LUBRICANTS

A1.1 In some cases a Brookfield viscosity at a single temperature may not adequately define the low temperature, low-shear-rate behavior of an automotive lubricant fluid. In those cases, Brookfield viscosity versus temperature plots may be useful.

A1.2 Brookfield viscosity versus temperature plots are made by measuring Brookfield viscosity at at least three temperatures and plotting a smooth curve of the logarithm of Brookfield viscosity against temperature. Commonly available semilog paper is suitable for these plots.

A1.3 When Brookfield viscosity versus temperature plots are used for interpolation, the interpolation temperature or viscosity must be within the range of measured data.

A1.4 Special temperature scales may be useful for some applications. Such scales would include the Kelvin instead of the Celsius measurement temperature and the reciprocal of the measurement temperature.

A1.5 The following precautions should be recognized to avoid misinterpretation of Brookfield viscosity versus temperature plots.

A1.5.1 Extrapolation beyond the range of measured data should be avoided because many automotive fluid lubricants are non-Newtonian at low temperature. The gel structure associated with such non-Newtonian behavior may undergo rapid changes with temperature that are not predicted by simple extrapolation.

A1.5.2 The ASTM viscosity-temperature graphs (Charts D 341) should not be used for extrapolation of Brookfield data or for linear interpolation over a wide temperature range. Again, the non-Newtonian character of many automotive fluid lubricants at low temperature is the reason this test method is not applicable.

A1.5.3 Brookfield viscosities involved in plots that are compared between laboratories must be taken at the same rpm in each laboratory. Because of non-Newtonian behavior, Brookfield viscosity is dependent on rpm. If different rpm measurements are taken in different laboratories, widely different viscosities may be reported.

A2. TYPICAL SAMPLE COOLING RATES IN BROOKFIELD AIR BATHS

A2.1 This annex is intended to serve as a guide to Brookfield bath manufacturers. Sample cooling rates in Brookfield baths are considered important because the gel structure of some automotive fluid lubricants is dependent on the rate of cooling. This gel structure influences apparent Brookfield viscosity.

A2.2 The temperature of a sample immersed in a precooled bath should follow the equation:

$$dS/dt = k(S - B) \quad \text{(A2.1)}$$

where:
S = sample temperature at observation time
t = elapsed time from start of cooling
B = bath temperature, and
k = cooling constant with units of time^{-1}.

Eq A2.1 solves to:

$$(S - B) = Ce^{Kt} \tag{A2.2}$$

where:
C = integration constant, and
e = base Napierian logarithms (2.71828+).

Eq A2.3 may be conveniently plotted as:

$$\ln \frac{(S - B)}{A} = \ln\ C + kt \tag{A2.3}$$

A2.3 When temperature is in degrees Fahrenheit, a sample in an average air bath cools with k values that may range between −0.12 and −0.040, averaging −0.08. C represents the sample-bath temperature difference at zero soak time. For the tests run, ln C ranged between 4.45 and 4.80. Baths that cool samples at rates defined by these limits and meet other method requirements are satisfactory for Brookfield viscometry of automotive fluid lubricants.

A3. USE OF A NEWTONIAN REFERENCE FLUID TO MONITOR BROOKFIELD VISCOMETER PRECISION

A3.1 *Abstract* —This annex outlines the calculation steps needed to determine control limits that show if the Brookfield system (temperature bath, viscometer spindle immersion depth, and viscometer) is operating within the limits determined as typical by extensive round robins of the method. If dial readings outside the determined control limits are found, or if a significant, continuing bias is found, check these common sources of error:

A3.1.1 Spindle immersion depth,
A3.1.2 Temperature calibration, and
A3.1.3 Mechanical condition of the viscometer and spindle.

A3.2 *Known Calculation Constants*:

A3.2.1 The viscosity-temperature function of the Newtonian reference fluid is stated on its label.
A3.2.2 Brookfield calibration factors are known from the Brookfield instrumentation book and Section 11.
A3.2.3 Observed dial reading and rpm for the reference fluid.
A3.2.4 Set temperature.

A3.3 *Calculations* :

A3.3.1 Determine the reference fluid viscosity at the set test temperature. If the set test temperature is not listed on the reference fluid label, the viscosity at that temperature can be interpolated through the equations in the appendix of Charts D 341 because the reference fluid is waxfree and Newtonian.

A3.3.2 From the reference viscosity, known rpm, and Brookfield constant, calculate the expected dial reading.

Expected dial reading = (reference viscosity at set test temperature)/(Brookfield factor for the rpm used)

A3.3.3 Determine the deviation of the observed dial reading from the expected dial reading.

deviation = observed dial reading − expected dial reading

A3.3.4 *Interpretation*:

A3.3.4.1 If the rpm

is	1.5	3.0	6.0	12.0	30.0	60.0
and the deviation						
is greater than ±	5.0	4.5	4.0	4.0	3.5	3.5

Then there is probable error in one or more of the following: spindle immersion depth, temperature control or calibration, and viscometer malfunction. Carefully check the equipment and make any necessary adjustments. Rerun the samples.

A3.3.4.2 If the rpm

is	1.5	3.0	6.0	12.0	30.0	60.0
and the deviation						
is greater than ±	9.0	7.0	6.5	6.5	6.0	5.0

Then there is high probability that temperature control is faulty or that there is serious operational error.

A3.3.5 *Example*:

Set test temperature	–40°C
Reference fluid viscosity	99 510 cP
3 rpm Brookfield factor	2 000
Observed dial reading at 3 rpm	51.2

$$\text{Expected dial reading} = \frac{99\ 510}{2\ 000} = 49.8 \qquad \text{(A3.1)}$$

Deviation = 51.2 − 49.8 = 1.4 at 3 rpm
Interpretation − Satisfactory run.

A4. ESTIMATION OF APPARENT RUN TEMPERATURE FROM OBSERVED BROOKFIELD VISCOSITY OF A NEWTONIAN REFERENCE FLUID

A4.1 This annex provides a way to estimate the apparent temperature at which the reference sample was run. Although the most probable cause of significant deviation between the set test temperature and calculated apparent run temperature is error in the temperature control and monitoring system, errors in spindle immersion depth and viscometer malfunction can also cause noticeable deviations. If viscometer function and spindle immersion depth are satisfactory, then the calculated deviation between set and apparent run temperature is a measure of the size of the temperature control and monitoring error.

A4.2 *Known Calculation Constants:*

A4.2.1 The viscosity-temperature function of the standard reference fluid is listed on the label.
A4.2.2 Brookfield calibration factors are in Section 8.
A4.2.3 The dial reading and rpm for the standard reference fluid are observed.
A4.2.4 The set test temperature is a defined test condition.

A4.3 *Calculations* :

A4.3.1 Determine the Brookfield viscosity.
Brookfield viscosity = observed dial reading
× Brookfield calibration factor

A4.3.2 Determine constants *A* and *B* from Eq A2.2, Eq A2.3, and Eq A3.1 in the appendix Charts D 341. Use two reference fluid viscosities at two temperatures near the set test temperature.

A4.3.3 Calculate *Z* from Brookfield viscosity and Eq A2.3 in the appendix of Charts D 341.

A4.3.4 Use the following form of Eq A2.2, in the appendix of Charts D 341 to calculate *T*, the apparent run temperature in °F.

$$T = (\text{antilog}\ (A - \log\log Z)/B) - 460 \qquad \text{(A4.1)}$$

A4.3.5 Calculate $T = T$ − set test temperature.

A4.4 *Example* : Set temperature, −30°F (−34.4°C)

Observed dial reading at 12 rpm, 49.5
Reference fluid viscosity at −20°F (−28.9°C), 11 360
Reference fluid viscosity at −30°F (−34.4°C), 28 580
Brookfield factor at 12 rpm, 500
Brookfield viscosity = 49.5 × 500 = 24 750
from the Appendix Charts D 341,

Eq A2.3	*Z* (−30°F)	=	28 580.7
Eq A2.3	*Z* (−20°F)	=	11 360.7
Eq A2.2	*A*	=	11.44162
Eq A2.2	*B*	=	4.09827
Eq A2.3	*Z* observed	=	24 750.7

T = (antilog (11.44162 – log log 24 750.7)/4.09827) – 460
T = 28.52°F or –33.62°C
T = 1.48°F or 0.78°C

A4.5 *Interpretation* —The 0.78°C temperature deviation from set point is more than twice the allowed 0.3°C bath temperature variation. Probable temperature control or measurement error is indicated. However, possible severe spindle immersion depth error or viscometer malfunction should also be checked. Data from samples run in this test series should not be reported.

APPENDIXES

(Nonmandatory Information)

X1. LOW-TEMPERATURE, LOW-SHEAR-RATE BEHAVIOR OF NON-NEWTONIAN AND NEWTONIAN FLUIDS IN BROOKFIELD VISCOMETRY

X1.1 This appendix illustrates why Brookfield viscosity is often a function of viscometer rpm. At low temperature many mineral oil-based lubricants develop shear-rate-sensitive wax or wax-polymer gels. Ideally, this gel appears to have a finite rigidity or strength which is reflected in Brookfield measurements as the apparent stress (dial reading) needed before the spindle begins to rotate.

X1.2 The Newtonian fluid in Fig. X1.1 has no yield stress and the dial reading is directly proportional to the spindle rpm. Its Brookfield viscosity is proportional to the slope (dial reading/rpm). This slope does not vary with rpm.

X1.3 The illustrative dial reading-rpm function of the non-Newtonian oil Fig. X1.1 has a finite dial reading when extrapolated to 0 rpm. This 0 rpm extrapolated dial reading is the apparent yield stress. Because of the apparent yield stress, the viscosity of the non-Newtonian fluid is a function of rpm as follows:

Case	Spindle, rpm	Dial Reading	Slope	Brookfield Apparent Viscosity (mPa·s)
A	12	36	3	18 000
B	30	60	2	12 000

X1.4 For a non-Newtonian fluid, the strong dependence of viscosity on rpm is a result of the definition of the Brookfield slope. This slope is *always* calculated from a line drawn from the origin (the 0 dial reading/0 rpm point) to the observed dial reading/set ppm point. When an apparent yield stress exists, this slope is much greater at low rpm than at high.

X1.5 *Because of the large effect of apparent yield stress on Brookfield viscosity, it is imperative that fluid lubricants of the same viscosity classification be compared at the same rpm.*

X1.6 Ideally, apparent yield stress can be subtracted from dial readings to give a constant dial reading/rpm slope. This slope can be used with an appropriate calibration constant to give a “flow” viscosity, which may be useful for correlation with some low-temperature performance data.

X1.7 In practice, the dial reading/rpm functions may not be completely linear. Shear degradation of gel structure or alignment of flow units, or both, may make the dial reading/rpm function slightly concave toward the rpm axis. Because long measurement times are often needed for a complete dial reading/rpm determination, sample heating may also cause some curvature.

X2. TYPICAL REFERENCE FLUID VISCOSITIES

X2.1 The viscosity-temperature function of each standard reference fluid is listed on its bottle by the supplier. The following table lists typical viscosity values:

Reference Fluid	Temperature, °C	Typical Viscosity, mPa·s	Maximum Viscosity Change Due to 0.3°C, mPa·s
N27B	−28.9	5 300	245
	−34.4	12 750	701
	−40.0	36 940	2 324
Reference Fluid	**Temperature, °C**	**Typical Viscosity, mPa·s**	**Maximum Viscosity Change Due to 0.3°C, mPa·s**
N115B	−6.7	5 970	254
	−12.2	13 360	591
	−17.8	32 310	1 589
	−23.3	81 460	4 823
	−28.9	253 700	16 972

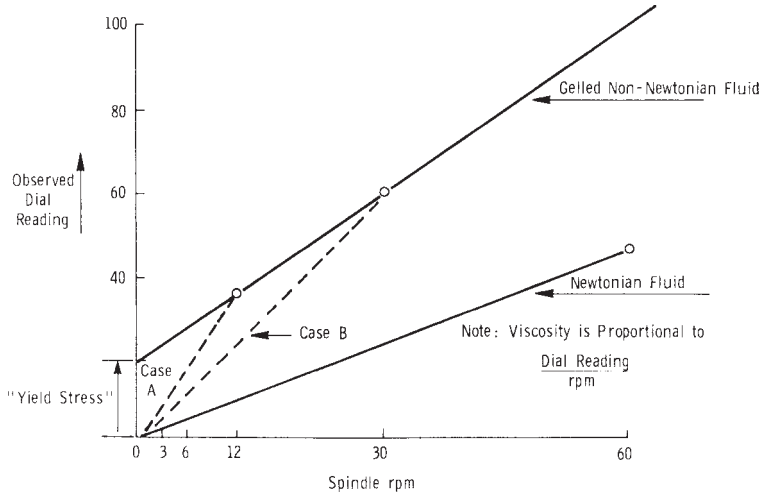


FIG. X1.1 Diagram of Brookfield Dial Reading Versus rpm

X3. SHEAR STRESS AND SHEAR RATE FORMULAS FOR BROOKFIELD LV VISCOMETERS WITH LV-4 SPINDLES

X3.1 *Shear Stress (or Yield Stress):*

$$T = 1.253 \times M \tag{X3.1}$$

where:
T = shear stress, Pa,
M = dial reading, and,
1.253 = constant determined from spindle dimensions and the viscometer's spring constant.

X3.2 *Shear Rate* (at the wall of LV-4 spindle in a 22.25-mm inside diameter test cell):

$$S = 0.2156 \times \text{rpm} \tag{X3.2}$$

where:
S = shear rate, s^{-1},
rpm = rotational speed, rpm, and
0.2156 = constant dependent on spindle radius and test cell internal diameter.

NOTE X3.1—Equations are derived from Brookfield Engineering Laboratories, Inc., literature. Brookfield Engineering Laboratories should be consulted for more detailed derivations.[9]

[9] Available from Brookfield Engineering Laboratories, Inc., Stoughton, MA 02072.

X4. DETERMINATION OF THE VISCOSITY OF HYDRAULIC OILS

X4.1 This appendix provides information regarding the precision of this test method for determining the apparent viscosity of hydraulic oils. Six hydraulic oils, covering a temperature range of –10°C, –15°C and –20°C and a viscosity range of approximately 500 to 1900 mPa·s were analyzed by ten laboratories. The results of the 1993 interlaboratory cooperative test program are available from ASTM Headquarters.[10]

X4.2 Test Method D 2983–87 was used in this study with the following changes to Paragraph 10.3:

X4.2.1 Samples were conditioned at 80 ± 3°C for 60 ± 5 min and allowed to cool at room temperature for a minimum of 60 min prior to transferring to the cooling bath.

X4.2.2 The appropriate reference fluids were run at the beginning and end of each set of samples to ensure the sample temperature change due to the opening and closing of the cold cabinet was not greater than 0.4°C.

X4.2.3 An attempt was made to complete the testing within 30 s after the sample was removed from the cold cabinet; the testing was completed within no longer than 60 s.

X4.2.4 The test series was completed within 1 h so that a maximum soak time did not exceed 17 h for any sample.

X4.3 *Precision* :

NOTE X4.1—The poor precision of this hydraulic method is directly related to the size of the spindle used (No. 4 spindle used in the Test Method D 2983 hydraulic round robin). The reason is that the viscosity of these fluids is much lower than what the original test method was designed to handle. These lower viscosities cause the torque readings from the viscometer to be in a less accurate zone. Further work is being performed with a No. 3 cylindrical rotor to develop increased torque suitable for a more accurate zone for the viscometer.

X4.3.1 The precision of this test method as determined by ADJD6300 (formerly known as ASTM D2PP program) is set forth below. It was determined with samples varying from 500 to 1700 mPa·s, and is valid within this range of viscosities. Precision will be subject to increasing uncertainties as measured viscosities depart from this range.

X4.3.2 *Repeatability*— The difference between successive test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material would, in the long run, and in the normal an correct operation of the test method, exceed the following value only in one case in 20.

$$\text{Repeatability} = 44 \text{ mPa·s}$$

X4.3.3 *Reproducibility*— The difference between two single and independent results, obtained by different operators working in different laboratories on identical test material would, in the long run, and in normal and correct operation of the test method, exceed the following value only in one case in 20.

$$\text{Reproducibility} = 141 \text{ mPa·s}$$

[10] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D02-1486.

SUMMARY OF CHANGES

Subcommittee D02.07 has identified the location of selected changes to this standard since the last issue (D 2983–03~~4~~) that may impact the use of this standard. (Approved ~~Feb.~~ May 1, 2004.)

(1) Added new sentence to the end of 6.1.

Subcommittee D02.07 has identified the location of selected changes to this standard since the last issue (D 2983–03) that may impact the use of this standard. (Approved Feb. 1, 2004.)

(1) Modified Fig. 2.

Subcommittee D02.07 has identified the location of selected changes to this standard since the last issue (D 2983–02b) that may impact the use of this standard. (Approved Aug. 10, 2003.)

(1) Modified 6.9 and 6.9.1 to allow liquid bath temperatures to be verified with a device other than a submersible thermometer.
(2) Added more details to 6.2 in order to properly check for wobble in the rotor.
(3) Added ~~Note 2~~ note alerting users to verify that viscometers have been properly calibrated prior to use.

Subcommittee D02.07 has identified the location of selected changes to this standard since the last issue (D 2983–02a) that may impact the use of this standard. (Approved Nov. 10, 2002.)

(1) Revised the text in 8.2.2 and 8.3.